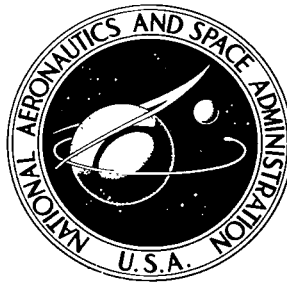


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A REAL-TIME SPACE STATION DYNAMICS AND CONTROL SYSTEM SIMULATION

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A REAL-TIME SPACE STATION DYNAMICS AND CONTROL SYSTEM SIMULATION

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SUMMARY

A real-time computer-hardware simulation for the investigation of space station dynamics and control problems is described. The simulation utilizes full-scale control moment gyro (CMG) hardware mounted on a moving base simulator, a manual control console, and a Control Data (CDC) 6600 digital computer to represent a space station and its control system. The digital computer software is programed in modular form by using separate subroutines or modules to represent the simulated spacecraft, onboard control computer, isolated experiment packages, and other disturbance or dynamics functions associated with space station operation. A complete functional and operational description of major elements of the space station simulation is included.

INTRODUCTION

The NASA manned space station program supports earth surveys, astronomy, and technology development for space systems and operations. A space station meets these objectives by providing a general purpose laboratory in earth orbit for extended periods of time. Support for the scientific and engineering experiments with this laboratory involves highly varied and complex control tasks. In addition, the long lifetime requires that system malfunctions be detected and diagnosed. It is therefore desirable to simulate the operation of such a system in conjunction with state-of-the-art control system hardware in order to determine research areas where further developments are needed. This overall control system simulation could then be used as a focal point for performing research on the space station control problem.

A conceptual design of a typical space station, proposed for the late 1970 decade is shown in figure 1. Such a station would have a 10-year lifetime to perform scientific and engineering experiments in near-earth orbit. The typical example of figure 1 has been generally configured to support a 9- to 12-man crew and be capable of performing a wide variety of scientific and engineering experiments. The complex structural configuration and extensive experimental program control tasks and pointing requirements complicate the design of an integrated control system for this spacecraft.

A space station simulation has been developed to investigate space station control problems and to develop and verify the performance of an integrated control system concept for the space station mission. This simulation is being used to develop CMG system control laws, spacecraft maneuver logic, a CMG system fault isolation and repair system, and experiment module control techniques. This report comprises a detailed description of the space station simulation operation characteristics and program software and includes typical results for several space station control tasks.

SYMBOLS

Values are given in both SI and U.S. Customary Units. The measurements and calculations were made in U.S. Customary Units.

G	actual CMG output torques, N-m (ft-lb)
H_T	total CMG system momentum, N-m-sec (ft-lb-sec)
I_{XX}	total spacecraft inertia for X-axis, kg-m ² (slug-ft ²)
I_{YY}	total spacecraft inertia for Y-axis, kg-m ² (slug-ft ²)
I_{ZZ}	total spacecraft inertia for Z-axis, kg-m ² (slug-ft ²)
K_ϕ	displacement gain for X-axis, N-m/rad (ft-lb/rad)
$K_{\dot{\phi}}$	rate gain for X-axis, $\frac{\text{N-m/rad}}{\text{sec}}$ $\left(\frac{\text{ft-lb/rad}}{\text{sec}}\right)$
K_θ	displacement gain for Y-axis, N-m/rad (ft-lb/rad)
$K_{\dot{\theta}}$	rate gain for Y-axis, $\frac{\text{N-m/rad}}{\text{sec}}$ $\left(\frac{\text{ft-lb/rad}}{\text{sec}}\right)$
K_ψ	displacement gain for Z-axis, N-m/rad (ft-lb/rad)
$K_{\dot{\psi}}$	rate gain for Z-axis, $\frac{\text{N-m/rad}}{\text{sec}}$ $\left(\frac{\text{ft-lb/rad}}{\text{sec}}\right)$
M_c	commanded CMG torques, N-m (ft-lb)
M_F	filtered command CMG torques, N-m (ft-lb)
$\dot{\alpha}$	CMG outer gimbal rate, deg/sec

$\dot{\beta}$	CMG inner gimbal rate, deg/sec
φ, θ, ψ	spacecraft Euler angles, rad
$\dot{\varphi}, \dot{\theta}, \dot{\psi}$	spacecraft Euler rates, rad/sec
θ_c	commanded spacecraft Euler angle (Y-axis), rad
$\dot{\theta}_c$	commanded spacecraft Euler rate (Y-axis), rad/sec
ω	spacecraft body rates, rad/sec

Subscripts:

c	command
e	error
X	spacecraft X body axis
Y	spacecraft Y body axis
Z	spacecraft Z body axis

SIMULATION DESCRIPTION

A schematic of the overall space station simulation is shown in figure 2. The hardware necessary for this simulation is located at various remote sites and is linked to a central computer by long trunk lines. Communication functions (input and output) between the central computer and the hardware are indicated in the figure by arrows.

The central computer is a CDC 6600 digital computer programed to operate in a real-time mode. The overall simulation is controlled from a simulation control station shown in figure 3 which includes a data entry keyboard, an on-line typewriter, time history recorders, and a cathode-ray tube (CRT). Represented on the digital computer are the spacecraft dynamics, CMG system control computer software, experiment package models, and external disturbance equations. The computer also performs the computations, logic, and input and output operations to communicate with the simulation hardware.

The CMG system, shown schematically in figure 4, consists of three double-gimbaled CMG's aligned with the spacecraft axes. The basic operation of this system is described

in reference 1. The full-scale laboratory prototype CMG hardware used in this simulation has a momentum storage capacity of 1355.8 N-m-sec (1000 ft-lb-sec) per gyro. The actual CMG hardware is shown in figure 5 mounted on board a moving base simulator or control flight test bed (CFTB). The CFTB is a three-axis servo table driven by the computer to reproduce the calculated spacecraft motions and provide a dynamic test environment for the CMG system. The computer generates CMG system gimbal rate commands. The CMG gimbal angles and output torques from the hardware are measured and transmitted back to the computer to be used in the CMG system control computer computations and the spacecraft dynamics. The central computer also contains onboard checkout and fault-isolation system software which continuously monitors the CMG system components to detect and repair failures.

The pilot control console shown in figure 6 provides the displays and manual controls for the various spacecraft modes of operation. Mode control logic allows the astronaut to control spacecraft attitude by commanding the CMG system, to point telescopes or tracking cameras by commanding gimballed platforms, and to monitor manually the operation of the onboard checkout system. Displays are provided for the various control modes which show CMG system status, spacecraft motions, and experiment package visual tracking information. Manual inputs are generated by a three-axis hand controller which commands spacecraft rates or experiment package rates, depending upon the mode of operation selected. Mode selection is accomplished by means of buttons on the console.

Located under the console couch is a force measuring system, shown in figure 7, consisting of six load cells which measure the forces and moments generated by the astronaut motion. These crew disturbances are transmitted directly to the simulation as internal spacecraft disturbances. A second program option allows previously recorded crew disturbances to be read into the simulation from an analog tape.

A capability for future hardware addition, indicated in figure 2 by dashed lines, could include a sensor simulation system located within a facility containing simulated spacecraft sensor references. This system would consist of a small three-axis servo table supporting actual spacecraft sensor hardware and would be driven by the computer to duplicate the spacecraft motions. The sensor hardware would measure spacecraft errors with respect to solar, planetary, and stellar references and would transmit actual spacecraft sensor signals to the system.

The mathematical models in the CDC 6600 system represent the basic dynamics of the spacecraft and its control system and may be run in a completely simulated mode for analytical studies. Hardware may be added to enhance the realism of the simulation results and to test the control hardware in a closed control loop. Any combination of hardware may be incorporated in the simulation by selection of the proper control word which calls the subroutine associated with the operation of that hardware.

SOFTWARE DESCRIPTION

The Space Station Simulation Program software is written in modular form and includes a main or executive program and 13 associated subroutines as outlined in table I.

TABLE I.- SPACE STATION DYNAMICS SIMULATION MODULAR PROGRAM OUTLINE

Program element	Function	Compiler storage, octal words	Execute storage octal words	CDC 6600 cycle time, milliseconds
Main Program - SPACE	Subroutine executive Mode controls Data input/output operations Rigid spacecraft equations	57 500	12 303	7.61
Subroutine INTEGR	Spacecraft and CMG system integration - rigid and flexible bodies	40 300	616	
Subroutine MOMENTM	CMG system momentum calculations (LRC & MSFC) and steering law and isogonal correction	46 100	2 636	
Subroutine FLEX	Spacecraft flexibility (ATM)	40 260	557	1.4
Subroutine HARD	CFTB and CMG hardware commands and communications	41 600	1 347	0.25
Subroutine CREW	Crew motion disturbance calculations (Input from tape or couch)	37 200	473	0.6
Subroutine EXPACK	Experiment package dynamics and associated integration	42 000	1 413	2.4
Subroutine CONSOLE	Manual control console logic and communication and a console static check	40 300	632	0.6
Subroutine DEE	Digital drive or manual console display	----	76	--
Subroutine CATIS	Computer-augmented camera tracking equations	40 700	1 074	3.4
Subroutine SMART	Monitor and diagnostic for CMG system	63 300	7 657	0.53
Subroutine VARFORM	Selects proper format statement number for on-line typewriter encode operation			
Subroutine CONVTIME	Obtains time of day in real time for on-line typewriter printout			
Subroutine SELECT	Manual monitor access to SMART for manual console operation			

A flow diagram of the simulation software, including subroutine notation, communication, and hardware interface, is shown in figure 8. Detailed discussions of the main program and all subroutines are included in appendix A. The main program (SPACE), the spacecraft motion integration routine (INTEGR), and CMG system control computer software (MOMENTM) make up a basic or fundamental program which must be loaded for all simulation runs. These three elements completely represent a rigid spacecraft and its integrated CMG control system. All remaining subroutines represent subsystem or special conditions associated with the space station or simulation operation.

The main program SPACE contains the system mode controls (including RESET, HOLD, and OPERATE modes) for communications between the program and the CDC 6600 computer. These mode controls are necessary to maintain the real-time status or proper

time synchronization of the computer operations. SPACE also acts as an executive for spacecraft subroutines, calling the proper subroutine (on option) as its calculations are required by the simulation. A complete outline of these executive operations is given in appendix A. All data input and output operations are controlled from the main program. The only computations performed by SPACE are the CMG control torques and the rigid-body accelerations.

SUBROUTINE DESCRIPTIONS

The following descriptions refer to the subroutines mentioned in figure 8. Subroutine INTEGR calculates the total spacecraft motions including flexible and rigid-body contributions by using a fourth-order Runge-Kutta integration scheme.

Subroutine MOMENTM represents the CMG control computer and is written in two parts. The first part consists of maneuver logic which computes an Euler eigenvector in space about which the spacecraft must rotate to acquire the command angles simultaneously. The maneuver logic involves calculations of total CMG momentum and vehicle momentum. A certain percentage of the available CMG momentum is then allocated for the maneuver and the required CMG command moments are calculated. The command moments are filtered by a four-pass Runge-Kutta digital approximation to fourth-order filters prior to being sent to the CMG steering law. The second part of MOMENTM contains the CMG steering law which is an exact inversion of the CMG system transfer function. Isogonal-correction (ref. 2) gimbal-rate calculations which permit the CMG system to avoid the adverse gimbal orientations, where control is lost, are available on option.

Subroutine FLEX solves the modal equations for seven modes of the flexible spacecraft. Bending model characteristics are supplied by the input. The flexible spacecraft motions are then summed with the rigid-body contributions in the main program.

Subroutine HARD handles all communications with the CMG and table hardware. HARD reads the CMG gimbal angles and output torques which are used as inputs to the CMG control computer and spacecraft dynamics equations. It then transmits the control computer output and spacecraft motions as commanded CMG gimbal rates and table rates and positions to the hardware. HARD also provides the capability to use any combination of actual CMG hardware and simulated CMG dynamics to make up the CMG system. This feature offers greater flexibility in simulation operation.

Subroutine SMART represents the computer software for an onboard fault isolation and repair system (ref. 3) which monitors the performance of the CMG hardware. This routine transmits parallel binary commands to a relay tree which addresses individual CMG components. The component performance is then compared with reference values and when an out-of-tolerance condition is detected, a diagnostic logic scheme determines

the specific malfunction and commands are issued to a second relay tree to replace faulty components. For all errors detected by the diagnostic scheme, an on-line typewriter message is generated for analysis by the operator. These typewriter messages, shown in figure 9, inform the operator that a CMG system failure has been detected and provides him with the time of failure detection, the faulty component, the average output of that component at the time of failure detection, and the action taken or requested by the computer. The failure message is typed immediately upon discovery of the bad system condition and completion of the diagnostic or repair operation. Subroutines VARFORM and CONVTIM are modified subroutines from the computer library at the Langley Research Center and were used in coding the diagnostic message for an on-line typewriter. Subroutine SELECT provides the capability for a pilot at the manual control console to override the automatic monitor in subroutine SMART and to address and monitor directly any CMG component.

Subroutine CONSOLE contains the complete logic required by the mode control functions and operational requirements of the pilot control console. This subroutine includes logic to interpret manual inputs properly and to provide proper displays for the various modes of console operation. Typical console operations include overall spacecraft control, astronomical telescope pointing, and gimballed camera package operations. Both manual inputs and console displays include discrete (switch and indicator light) and analog (hand controller and meter display) functions.

Subroutine CREW generates crew motion forces and moments by use of analog signals from either the load cell array or prerecorded analog tape. The tape signals contain force and moment information directly so that the only function of CREW is to provide proper scaling. The load cell signals must be transformed into spacecraft coordinates and summed to form the forces and moments in real time generated by pilot operation of the manual console.

Subroutine DEE is a special-purpose routine which generates and transmits digital spacecraft attitude information to a display located on the manual console. This routine is used by subroutines CONSOLE and CATIS.

Subroutine EXPACK represents the dynamics and the control system for a gimbal-mounted astronomical telescope. The telescope mount gimbals are servo driven to compensate for the main spacecraft motions and to provide much more precise pointing of the telescope package. Subroutine EXPACK contains the complete package dynamics and includes a four-pass Runge-Kutta integration scheme and a complete representation of the gimbal torque control loop. The telescope package is manually controlled by a pilot at the manual control console by using a television display of the telescope target.

Subroutine CATIS represents a gimbal-mounted camera capable of tracking and photographing targets on the surface of the earth. To achieve the desired tracking accuracy (± 1 sec), a computer extrapolation technique is utilized to augment the pilot's tracking

commands. This computer routine samples the pilot inputs and extrapolates these inputs by using either a Taylor series expansion or a polynomial curve fit. The computer then issues the extrapolated commands to the camera package so that the pilot is able to achieve more precise control. This routine also incorporates orbital geometry equations and commands the spacecraft to fly in a local vertical mode. Camera dynamics are included and the pilot uses a visual display of the target.

REAL-TIME DEFINITION

As is true of all digital computation, the real-time solution of a set of differential equations is a discrete or step process. The time it takes for each step is called the frame time. At the beginning of each frame, the computer reads inputs (signals from hardware), and at the end of each frame it writes outputs (signals to hardware). During each frame, the computer must do all calculations necessary to advance the equations of motion one integration step. The time it takes to do these calculations is called cycle time. Obviously, the cycle time must be less than the frame time. A summary of cycle times for each program element is shown in table I. The basic simulation can be run with a cycle time of 7.61 milliseconds, whereas the complete simulation requires a cycle time of 18.69 milliseconds. The space station simulation operates at 32 frames or iterations per second, so that the frame time is 30.125 milliseconds.

Also shown in table I are the storage or memory requirements for compilation and execution of the space station simulation. Each program element is converted from FORTRAN to machine language by a system compiler. This operation is performed serially so that the entire simulation may be compiled within the compiler storage requirement for the largest element. The execute storage represents the memory required by the program elements after conversion to machine language. The total execute storage for the simulation equals the sum of the individual storage requirements of all elements. The basic simulation can be stored in a memory of 15 757 octal words and the complete simulation requires 35 732 octal words of storage. Real-time system overhead requires approximately 45 000 octal words; thus, a total execute storage of 103 000 octal words is required for the complete simulation.

SIMULATED SPACECRAFT CHARACTERISTICS

The space station configuration shown in figure 1 is represented in the space station simulation. The spacecraft total inertias for this configuration are:

$$I_{XX} = 1\,221\,300 \text{ kg-m}^2 \text{ (900\,000 slug-ft}^2\text{)}$$

$$I_{YY} = 7\,870\,600 \text{ kg-m}^2 \text{ (5\,800\,000 slug-ft}^2\text{)}$$

$$I_{ZZ} = 7\,599\,200 \text{ kg-m}^2 \text{ (5\,600\,000 slug-ft}^2\text{)}$$

The spacecraft dynamics model contains seven (7) active flexible modes with bending frequencies of 0.848, 0.911, 2.87, 3.548, 5.037, 9.847, and 12.491 rad/sec. Figure 10 shows a schematic of a typical control system loop for one spacecraft axis. The spacecraft sensors are presently assumed to be ideal. The CMG system (fig. 4) is commanded by a rate plus displacement control law. The control law gains are:

$$K_{\phi} = 62\,376 \text{ N-m/rad (46\,000 ft-lb/rad)}$$

$$K_{\dot{\phi}} = 553\,173 \frac{\text{N-m/rad}}{\text{sec}} \left(408\,000 \frac{\text{ft-lb/rad}}{\text{sec}} \right)$$

$$K_{\theta} = 325\,440 \text{ N-m/rad (240\,000 ft-lb/rad)}$$

$$K_{\dot{\theta}} = 2\,101\,800 \frac{\text{N-m/rad}}{\text{sec}} \left(1\,550\,000 \frac{\text{ft-lb/rad}}{\text{sec}} \right)$$

$$K_{\psi} = 637\,320 \text{ N-m/rad (470\,000 ft-lb/rad)}$$

$$K_{\dot{\psi}} = 2\,861\,160 \frac{\text{N-m/rad}}{\text{sec}} \left(2\,110\,000 \frac{\text{ft-lb/rad}}{\text{sec}} \right)$$

for the X, Y, and Z axes, respectively. The CMG control loop also contains fourth-order bending filters to isolate the CMG from the high frequency spacecraft bending modes. Cutoff frequencies for these filters are 2, 1.25, and 1.9 rad/sec for the X, Y, and Z axes, respectively. The commanded CMG torques M_F are limited to 406.87 N-m (300 ft-lb). The CMG system steering law is an exact inversion of the CMG system characteristic equations. The steering law commands to the CMG gimbals are limited to 3.5° per second by hardware constraints. The individual CMG momentum capacity for the space station control system is 4068.9 N-m (3000 ft-lb) giving a total system envelope of 12 206.7 N-m (9000 ft-lb) about any spacecraft axis. The maneuver logic commands 85 percent of the available CMG system momentum to be used for spacecraft maneuvers.

The space station experiment package is mounted on double gimbals for pitch and yaw pointing controlled by the dc torquers at the ends of each gimbal. The package mass is 2331.465 kg (5140 lb) and the inertia is the 4478.1 kg-m² (3300 slug-ft²) about the gimbal axes. The dc torquers have torque limits of 9.492 N-m (7 ft-lb) and produce an available torque of 18.984 N-m (14 ft-lb) on each package axis.

SIMULATED SPACE STATION PERFORMANCE

Simulation runs have been made to demonstrate the performance of the space-station control system. The prototype CMG hardware was included in the simulation for these runs. Several typical space station control tasks such as large maneuvering, failure mode operation, and experiment package pointing were considered. The results are felt to be typical of space-station performance.

Figures 11 and 12 illustrate the maneuver capability of the space station CMG control system. Figure 11 shows results for a simultaneous 57.3° maneuver about all three spacecraft axes. The system maneuvers smoothly with three-axis acquisition in approximately 11.5 minutes. The total system momentum H_T was initialized to zero and builds up to a constant value of 85 percent of the available momentum. This momentum is imparted to the spacecraft which maneuvers at constant rates to the command attitude. It can also be seen in figure 11 that the actual CMG system torques G responded exactly to the command M_F and indicated that the exact inversion steering law yields linear control. Figure 12 illustrates the maneuver logic and steering law performance during CMG failure conditions. The maneuver commands are simultaneous X, Y, and Z axis maneuvers of 6° , 3° , and 3° , respectively. Spacecraft rates and attitudes are shown for a system with all three CMG's operating, failure of CMG 1, failure of CMG 2, and failure of CMG 3. As seen in figure 12, the system with one CMG failed responds almost as well as the complete system although it does require a longer period of time to complete the maneuvers, since less momentum is available for the maneuver because of the CMG failure. The steering law, which is set up to compensate for CMG failures shows only a slight decrease in performance which is shown primarily on the X-axis response in figure 12.

Figure 13 illustrates the response of the experiment package control system to a step input of 10 arc-min. The command attitude has been obtained within 5 seconds and illustrates the high response of this control system.

CONCLUDING REMARKS

The space station simulation represents a general research tool for analysis of space station dynamics and control problems. The simulation provides linkage to control system hardware for evaluation in a closed control loop. It also provides manual inputs for the study of crew motion effects and pilot control capability. Real-time digital representation of spacecraft dynamics and control computer operations permits flexibility in evaluating various spacecraft configurations and rapid synthesis of control logic schemes.

The modular form used in writing the program permits study of cooperative subsystems such as experiment packages. Typical results are shown to illustrate the capabilities of the simulation. Complete detailed descriptions of simulation operations are given in the appendixes.

The space station simulation has been written, debugged, and utilized in the evaluation of several control techniques and of an automated onboard checkout system applicable to the space station mission. The simulation concept of linking prototype hardware to a simulated vehicle and control computer for closed loop performance analyses has been verified. The space station simulation will be used in the development of an integrated control system concept for the manned space station.

Langley Research Center,
National Aeronautics and Space Administration,
Hampton, Va., July 15, 1971.

APPENDIX A

PROGRAM OPERATION

This appendix includes more detailed discussions and functional descriptions of the major program elements. The major elements selected are intended to provide typical examples of simulation operations and to illustrate interfaces between the various program elements. The discussions, therefore, include a description of the sequence of computations and operations performed by each subroutine, the inputs and outputs required by each program element, and the communication functions and sequences. The discussion of each program element is concerned with the physical phenomena represented by each operation, rather than with the equations involved, so that this appendix outlines the structure of the computer program required to simulate the operation of a typical manned space station and the considerations for conducting an evaluation of prototype subsystem hardware in a closed control loop.

Main Program (SPACE)

Calls.- The program SPACE calls subroutines MOMENTM(I), INTEGR, FLEX, SMART(I), HARD(I), CONSOLE(I), EXPACK(I), CATIS(I), and CREW(I). Numbers in parentheses refer to parts of multisection subroutines, that is, SMART(1) - initialize in RESET, SMART(2) - OPERATE mode.

Function.- The functions of this program are overall program control, data input and output functions, and subroutine executive.

Required input and output.- SPACE contains all input and output functions for the total simulation; these functions are discussed in appendixes B and C.

Description.- SPACE contains the simulation mode controls necessary for interface between the space station simulation program and a real-time supervisor to maintain the real-time status of the simulation. The program flow is accomplished by a real-time supervisor called RTMODE which senses a mode control switch closure at the simulation console and then branches to the proper section of the program. There are three modes (OPERATE, HOLD, and RESET) available during real-time operation. The OPERATE mode performs integration of program equations and stores real-time data on a disk file. The HOLD mode functions like OPERATE except that it bypasses integration, and holds the integrals to the last computed value. The RESET mode gives initial values to the integrals.

A fourth mode TERMINATE is available for termination of a job and any post-processing required. As shown in figure 14, these four mode controls are actuated from the simulation control station panel by depressing the proper mode control switch. The

APPENDIX A – Continued

functions of these mode controls are discussed in further detail as SPACE operations are discussed. The first part of SPACE is not processed in real time and is mainly an initialization section for program variables such as: recorder scale factors, subroutine control words, spacecraft characteristics, and pilot-control-console scale factors. The input data are also read in here.

The RESET loop is the first section of the program in real-time operation. The initial values of integrals and the spacecraft and CMG system initial conditions are set. Initialization of subroutines selected for use is obtained by calling the subroutine initialization section. The main body of SPACE contains the calculations required and subroutine communication necessary for program operation. The sequence of operations are outlined in the following description.

Subroutine HARD(2) is called to obtain input from the CFTB and CMG hardware. For CMG simulation, the CMG gimbal angles involved are calculated. CMG gimbal resolver calculations are performed on either the calculated or measured gimbal angles. Subroutine MOMENTM(1) is called for CMG momentum calculations and commanded torques from the CMG control law. The control torques are calculated with the option of using calculated or measured CMG gimbal rates or summing the measured CMG torques. Subroutine CREW(2) is called to acquire crew motion torques and forces. The disturbances applied to the flexible spacecraft consist of crew motion forces and torques, experiment package torques, and CMG control torques. The rigid-body disturbances include constant antiparallel moments, aerodynamic torques, gravity gradient torques, and the experiment package torques.

With these torques, the rigid- and flexible-body dynamics equations can be solved and then integrated. Total spacecraft motion is then obtained by summing the rigid and flexible motions.

Subroutine EXPACK(2) represents the astronomical telescope experiment package equations. Subroutine MOMENTM(2) contains the CMG steering law calculations and also provides isogonal correction on option. Subroutine SMART(2) is called to monitor the CMG hardware. This monitor is timed to call SMART and thus sample another CMG component on specific intervals.

Subroutine CONSOLE(2) is called in order to communicate with the manual control console. SPACE handles the output signals (generated by CONSOLE) for the console displays, whereas CONSOLE reads the hand-controller input signals. The final operation by SPACE in real time is the scaling of outputs for the time-history recorders. The OPERATE cycle begins over unless the run has been completed (RESET mode) at which time any desired post-processing can be initiated.

APPENDIX A – Continued

SPACE operational sequence.- The operational sequence is as follows:

Initialization (Nonreal time)	<ul style="list-style-type: none"> Initialize recorder scale factors Initialize subroutine control words Initialize spacecraft characteristics Read data Initialize manual control console scale factors
Reset (Real time)	<ul style="list-style-type: none"> Set in initial conditions for spacecraft and CMG's Set initial conditions in the subroutines: <ul style="list-style-type: none"> Call SMART(1) Call EXPACK(1) Call HARD(1) Call CATIS(1) Call CONSOLE(1) Call CREW(1)
Operate (Real time)	<ul style="list-style-type: none"> Call HARD(2) Make simulated CMG gimbal angle calculations Make CMG gimbal resolver calculations Call MOMENTM(1) – CMG momentum calculations and commanded moments or torques Make control torque calculations: <ul style="list-style-type: none"> (1) Using calculated or measured CMG gimbal angles and rates or (2) Using measured torque signals Call CREW(2) to obtain crew motion torques and forces Obtain flexible spacecraft disturbances by summing: <ul style="list-style-type: none"> Torques – (a) Crew motion torques (CMX, CMY, CMZ) (b) Experiment package torques (c) Control torques Crew motion forces (FXF, FYF, FZF) Obtain rigid-body disturbances by summing: <ul style="list-style-type: none"> (a) Constant antiparallel moments (b) Experiment package torques Solve rigid body dynamics equations Compute rigid-body accelerations Call FLEX to compute bending motions Integrate flexible and rigid spacecraft equations Obtain total spacecraft motion (rigid and flexible)

APPENDIX A – Continued

Operate
(Continued)

Call EXPACK(2) to solve experiment package dynamics equations
Call MOMENTM(2) for control law calculation
Monitor timer for subroutine SMART
Calculation of CMG momentum for manual-control console displays
Call CONSOLE(2) for communications with the manual-control console displays and controls
Record output

Terminate

Subroutine MOMENTM(I)

Called by.- Subroutine MOMENTM is called by SPACE from OPERATE.

Function.- Calculates CMG momentum, steering law, and isogonal correction.

Required input.- The inputs are vehicle attitude and rate sensor signals, spacecraft attitude commands, CMG resolver signals, CMG gimbal limit, and CMG status indications.

Output.- The output is CMG gimbal rate commands.

Option.- The isogonal correction is called on option (ISOG = .T.)

Description.- Subroutine MOMENTM represents the CMG onboard control computer. The input and output functions of this subroutine are indicative of those used by an onboard computer and the operations performed are representative of the onboard computer software. The CMG momentum components for each spacecraft axis are computed for the maneuver logic, the steering law, and the isogonal correction. These momentum calculations take into account CMG failures as indicated by CMG status information generated by the onboard checkout system (SMART). The spacecraft maneuver logic calculates the Euler eigenvector about which the spacecraft must rotate to acquire the command attitudes. The CMG momentum available for the maneuver is calculated and used to determine command moments for the CMG system. Fourth-order bending filters, simulated digitally, are used to remove high-frequency bending components from the command moment signals. The filtered command moments are used in the second section of MOMENTM which contains the CMG steering law. The present steering law is an exact inversion of the CMG system transfer function and thus eliminates all CMG cross coupling. The steering law generates CMG gimbal rate commands for control of the spacecraft. Added to these gimbal rate commands are the isogonal corrections (ref. 2) which command the CMG system to maintain an umbrella configuration in order to avoid the antiparallel condition. The resulting total CMG gimbal rate commands are sent to the CMG system.

APPENDIX A – Continued

MOMENTM operational sequence.- The operational sequence follows:

- (1) Calculate CMG momentum for spacecraft principal axes
 - Calculate total CMG momentum
 - Determine maneuver logic
 - Calculate commanded moments
 - Calculate filtered moments
- (2) Make steering law calculations
 - Perform isogonal correction

Subroutine HARD(I)

Called by.- The subroutine HARD(I) is called by SPACE

- If I = (1), RESET – Reposition table and gyros
If I = (2), OPERATE – Read input
If I = (3), OPERATE – Transmit output

Function.- Its function is CFTB and CMG hardware commands and communications.

Required input.- Since HARD acts as communications between the main program and the CMG hardware, there are two sets of input for the subroutine:

- (1) Input from the main program:
 - (a) Initial CMG gimbal angles and rates
 - (b) Initial table rates and angles
 - (c) CMG gimbal rate commands
 - (d) Table rate and angle commands
- (2) Input from the hardware:
 - (a) Actual CMG gimbal angles and rates
 - (b) Measured torque components
 - (c) Actual table rates and angles

Output.- There are two sets of output for the subroutine:

- (1) Output to the main program:
 - (a) Measured torque sums
 - (b) CMG gimbal angles and rates
- (2) Output to the hardware:
 - (a) CMG gimbal rate commands
 - (b) Table commands (rates and angles)

APPENDIX A – Continued

Options. - Any combination of CMG hardware may be used

ICMG1 = .T. - selects hardware for CMG 1

ICMG2 = .T. - selects hardware for CMG 2

ICMG3 = .T. - selects hardware for CMG 3

For each actual CMG selected, gimbal angles are read. There are three options for obtaining the output torques:

- (1) Read the measured CMG torques directly (ITMS = .T.)
- (2) Read the actual CMG gimbal rates and compute the torques (IRATEM = .T.)
- (3) Assume perfect gyros by setting the rates equal to the commanded rates and computing the torques

Description. - The RESET section of HARD is an initialization section for scale factors and constants. It also positions the CFTB and CMG gimbals to an initial position required for the run. In the OPERATE loop there are two sections, one for input from hardware and one for output to hardware. CFTB rates and angles are read and then table attitude and rate errors are calculated. Depending on the combination of CMG hardware selected, the program will take each CMG in order, the gimbal angles being read first. If the rate mode has been selected, the CMG gimbal rates are read directly for the calculations of torques. If the ITMS mode is desired, then the measured torques are read at this point and the gimbal rates are set equal to zero to null the torque calculations. In the second section the CMG gimbal rate commands and CFTB commands are sent to the hardware. If, for some reason, a gyro is not in operation, that gyro command is nulled.

HARD operational sequence. - The operational sequence for HARD follows:

- (1) Initialize constants
 - Initialize scale factors used for CFTB and CMG gimbal reset commands
 - Initialize scale factors for CFTB rates and angles from hardware
 - Initialize scale factors for CFTB commands and commanded CMG gimbal angles
 - Issue reset commands to CFTB and CMG gimbals for initial positioning
- (2) Read CFTB rates and angles (special logic for inner gimbal because of continuous rotation)
 - Compute CFTB attitude and rate errors (commanded minus actual) and signal operator if the resultant error is outside of the desired limit
 - Check CMG 1 hardware
 - (1) Read gimbal angles
 - (2) For rate mode, read rates directly
 - (3) For ITMS mode, read measured torques and set gimbal rates = 0.0
 - Check CMG 2 and CMG 3 hardware in same manner
 - Sum measured torques if in ITMS mode

APPENDIX A – Continued

(3) Send Gimbal rate commands to CMG hardware

Send CFTB commands (angles and rates) to hardware (special logic for inner gimbal because of continuous rotation)

Null gyro commands if that gyro is not in operation during failure modes

Subroutine EXPACK(I)

Called by.- The subroutine EXPACK(I) is called by SPACE.

If I = (1), RESET

If I = (2), OPERATE

Function.- Its function is experiment package dynamics and associated integration.

Required input.- The experiment package dynamics require the spacecraft angular and linear accelerations at the package pivot point, total spacecraft body rates and inertial Euler angles, and manual inputs to the package servo drives.

Output.- The output includes

- (1) Experiment package torques for the spacecraft dynamics
- (2) Experiment inertial angles for the manual console display

Description.- EXPACK contains the complete dynamics equations for an external experiment package such as an astronomical telescope. This package is considered to be a separate body in space acted on by disturbances from the main spacecraft and by control torques from its servo control systems. The package servo control loops use information from simulated attitude sensors mounted onboard the package. Spacecraft linear and angular accelerations are transformed into package coordinates and resulting torques on the package are computed. The package accelerations are computed and a fourth-order Runge-Kutta integration routine included in EXPACK yields package rates and inertial angles. The roll axis is rigidly attached to the spacecraft except for a rack-and-pinion crank-around system so that its motions are identical to the spacecraft motions. The package inertial angles are used as sensor signals to the package servo drives. The simulated servo control loops and servo dynamics, by using inputs from the manual control console, yield package control torques which are used in the package equations of motion. The resulting total torques on the package are applied as disturbances to the main spacecraft equations of motion.

EXPACK operational sequence.- The EXPACK operational sequence follows:

- (1) Initialize the subroutine constants
- (2) Transform the linear and angular accelerations of the spacecraft at the pivot point from spacecraft coordinates to package coordinates

APPENDIX A - Continued

Solve the equations of motion for experiment package for all axes
Calculate the package control torques
Perform integration (Runge-Kutta)
Sum the experiment package torques on spacecraft

Subroutine CONSOLE(I)

Called by.- Subroutine CONSOLE(I) is called by SPACE.

If I = (1), RESET

If I = (2), OPERATE

Function.- Its function is manual control console logic and communication.

Required input.- Because CONSOLE acts as a communication link between the main program and the manual control console hardware, there are two sets of input for the subroutine:

(1) Input from the main program:

- (a) CMG status (operational CMG's and rate or torque mode of operation)
- (b) CMG total momentum and CMG momentum components about each spacecraft axis
- (c) Spacecraft angular errors and experiment package angular errors

(2) Input from hardware:

- (a) Three hand controller signals as commanded spacecraft rates
- (b) All discrete function switches associated with the console

Note that subroutine DEE must be loaded when this subroutine is used.

Output.- There are also two sets of output:

(1) Output to main program:

Hand controller commands to CMG control computer

(2) Output to hardware:

- (a) Analog display drive signals (CMG momentum)
- (b) Console discrete displays
- (c) Visual (TV) display drive signals (spacecraft or experiment package angular errors)

Option.- In the RESET loop a static check can be made on discrete signals being sent from the computer to the manual control console.

Description.- The first section of this subroutine contains the initialization of constants, the reset loop, and the console discrete static check logic.

APPENDIX A – Continued

The input for the digital display (DEE) is set up with an option of displaying the integral of the hand controller commands or the actual spacecraft angles. Discrete signals are sent to the manual control console for indication of CMG system status, simulation status, and maintenance and repair system.

There are four spacecraft modes of operation available and they are selected manually from the console. These four modes are STANDBY, maneuver and acquisition (M & A), inertial hold and maneuver (IH & M), and experiment package mode (EPS). In the STANDBY mode, no manual inputs are accepted from the hand controller. In M & A and IH & M modes, hand controller inputs are used as spacecraft rate commands. In the EPS mode, hand controller inputs are used as experiment package rate commands. The roll crank-around turns the experiment package about its roll axis and can be used in the EPS mode only with the hand controller disabled.

CONSOLE operational sequence.– The operational sequence is as follows:

- (1) Initialize the subroutine constants
 Make console static check (Optional)
- (2) Read input to digital display (integral of hand controller commands or actual spacecraft angles)
 Read discretes indicating CMG status
 Read discretes indicating simulation status
 Read discretes indicating maintenance and repair system
 Check for spacecraft operational mode:
 - (a) STANDBY – Accepts no manual input
 - (b) M & A or IH & M – Hand controller inputs are used as spacecraft rate commands
 - (c) EPS – Hand controller inputs are used for experiment package rate commands

The roll crank-around can be used only with the hand controller disabled
Check for fine and coarse sun-sensor fields of view

Subroutine CATIS(I)

Called by.– The subroutine CATIS(I) is called by SPACE.

If I = (1), RESET

If I = (2), OPERATE

Function.– Its function is to serve as a computer-augmented camera tracking information system.

APPENDIX A – Continued

Required input.- The only input required is the hand controller input and discrete hand controller scale factor changes from the manual control console. The lead term for the Taylor series is provided by a potentiometer signal from the program control station. Note that subroutine DEE must be loaded when using this subroutine.

Output.- The output to the spacecraft CMG control system commands the spacecraft to be precessed at orbit rate in a local vertical mode. The actual camera gimbal angles with respect to the spacecraft are used to drive the digital display on the manual control console.

Options.- The computer input has three options. These options are

- (1) camera-commanded angle
- (2) actual camera rate
- (3) camera command rate

There are two options on the computer augmentation prediction technique. These options are

- (1) Taylor series expansion
- (2) Polynomial curve fit

Description.- Subroutine CATIS represent the orbit geometry equations and the onboard digital computer software required to extrapolate a set of manual input for an earth target tracking camera. The orbit geometry is computed for a spacecraft in circular orbit and the spacecraft commands to hold local vertical and look angles to a specific target are generated. A rate command tracking camera servo loop is simulated and the tracking camera output or picture is displayed to the pilot by a television screen on the manual control console. The pilot uses a hand controller to track the desired target on this visual display. The onboard computer routine samples the resulting tracking information (see options) and extrapolates this data to generate commands to the tracking camera which will reduce the tracking task being performed by the pilot. As this computer augmentation becomes available to the tracking camera, the pilot is able to decrease the gain on his input and fine tune the tracking camera and thus achieve extremely accurate tracking.

The augmentation computer extrapolation software reads a number of input samples and averages these values to yield a point on the tracking curve. A variable number of these points are used to generate the required Taylor series or the polynomial coefficients for the curve fit routine. The derivatives for these routines are taken as the slope between the averaged points. Both the Taylor series expansion and the polynomial curve fit are taken about the last point read. The sampled data points are therefore shifted back for each new point read and the computer commands to the tracking camera automatically begin when the required number of arrays are filled.

APPENDIX A – Continued

CATIS operational sequence.– The CATIS operational sequence is as follows:

- (1) Initialize the subroutine constants
- (2) Solve tracking camera equations of motion
 - Solve orbit geometry equations
 - Conduct computer extrapolation routine:
 - (a) Sample input
 - (b) Shift data
 - (c) Compute averages
 - Compute terms of Taylor series or coefficients of the polynomial
 - Compute extrapolated camera rate command

Subroutine SMART(I)

Called by.– The subroutine SMART(I) is called by SPACE.

If I = (1), RESET

If I = (2), OPERATE

Calls.– This subroutine calls VARFORM, CONVTIM, and SELECT.

Function.– Its function is monitor and diagnostic routine for CMG onboard checkout system with typewriter output of detected failures.

Required input.– The required inputs are the input signal from CMG component being monitored, six manual address discretes, and two manual interrogation discretes. Note that subroutines VARFORM and CONVTIM must be loaded when this subroutine is used.

Output.– The outputs for this subroutine are six address discretes and six command discretes to the CMG hardware. Discrete display information is also provided to the manual control console.

Description.– Subroutine SMART represents the onboard checkout computer software for the Expeditionary Monitor and Maintenance Analyst (EMMA) described in reference 3. The SMART software routine contains two basic sections: a monitor routine which addresses and checks the output of the CMG hardware components, and a diagnostic scheme which isolates the specific component failure when a hardware output out-of-tolerance condition is detected. An overall block diagram of the EMMA system is shown in figure 15.

The monitor sets up six binary address discretes which are transmitted to a relay tree to address the particular CMG component to be checked. The component output is compared with a preselected reference value and if this value is within tolerance, the monitor routine sequences and sets up the address for the next component. A pilot at the manual control console can at any time override the automatic monitor and check any component desired. The logic for this operation is contained in subroutine SELECT.

APPENDIX A – Concluded

If an out-of-tolerance condition is detected by the monitor, a diagnostic scheme is called to isolate the specific failure. The diagnostic scheme addresses and checks components in its diagnosis. Once the exact fault is determined, a corrective action sequence is initiated to replace the failed component. This sequencer drives six command discretes which switch the hardware components in and out of the loop. The detected error, corrective action taken by the computer, and manual assistance required are stored within the computer and transmitted to an on-line typewriter.

APPENDIX B

PROGRAM INPUT

This appendix is primarily a tabulation of input data and associated formats, descriptions of variables, and explanations of options. Two forms are available for supplying the space station dynamics simulation with the necessary input information. The first is a card deck which is submitted with the program deck and initializes program variables. Other input is supplied from a data entry keyboard located on the program control station which permits variable changes to be made without resubmitting the program.

Card Input

The card input to the program is in two parts. The first uses a NAMELIST statement. NAMELIST provides input of character lists consisting of names and variables without reference to a format statement. Table B-1 lists the NAMELIST variables and a

TABLE B-1.- NAMELIST CARD INPUT VARIABLES

<u>Variable name</u>	<u>Description</u>
UJ (7,18)	Deflections and angles for flexible modes (7) normalized (X/XMAX)
PPHI (3,7)	Angular modal participation matrix assigns relative importance (magnitude) of mode shapes
PHI2 (3,7)	Modal participation matrix for linear acceleration at the experiment package attachment point
OOMEG (7)	Modal natural frequency
AKDP	Distribution gain for isogonal correction
AKR	Rotation gain for isogonal correction

description of each. The second part of the card input is submitted in an ordered list and is referenced to a specific format. This input follows the NAMELIST input in the deck. The variables included as card inputs are variables which usually remain constant for all runs. A listing and description of these variables is shown in table B-2.

APPENDIX B – Continued

TABLE B-2.- FORMAT CARD INPUT VARIABLES

<u>Variable name</u>	<u>Description</u>
ISUBXX } ISUBYY } ISUBZZ }	Spacecraft inertias
H	Individual CMG momentum
HH	Integration step size
TO	Initial time (t.)
OMEGXRO } OMEGYRO } OMEGZRO }	Initial rigid body rates
PHIRO } THETRO } PSIRO }	Initial rigid body Euler angles
ALPHA1O } ALPHA2O } ALPHA3O } BETA1O } BETA2O } BETA3O }	Initial CMG gimbal angles
PHIC } PSIC } THETC }	Commanded Euler angles
OMEGXC } OMEGYC } OMEGZC }	Commanded body rates
KPHI } KDPHI } KTHET } KDTHET } KPSI } KDPSI }	CMG system control law attitude and rate gains
KSLA } KSLB }	Steering law gains
W1 } W2 } W3 }	Bending filter break frequencies
POSLIM	CMG gimbal rate limit (deg/sec)
RHO	Damping coefficients of bending filters
ZETA	Spacecraft flexibility damping coefficient
GG	Gravity gradient gravitational constant
WG	Orbit rate
CMLIM	CMG system command torque limit

APPENDIX B – Continued

Keyboard Input

In addition to the card inputs, certain variables may be changed by the operator from the program control station through a data entry keyboard. (See fig. 14.) The data entry keyboard communicates with a system subroutine, CHANGE, which provides the capability to change parameters in central memory without removing the program from the computer and to display simultaneously the value of the parameter on a digital display located on the program control station. Desired variables for input from the keyboard have been defined in specific arrays (by use of equivalence statements) and are assigned a corresponding display address by the computer as follows:

Central memory array	Display address
VAR(I)	I
INTEG(I)	I + 200
LOGIC(I)	I + 300

A listing and a description of these variables are shown in table B-3.

TABLE B-3.- KEYBOARD INPUT VARIABLES

<u>VAR</u>	<u>Variable name</u>	<u>Description</u>
1	PHIC	Commanded spacecraft angles
2	THETC	
3	PSIC	
4	OMEGXC	Commanded spacecraft rates
5	OMEGYC	
6	OMEGZC	
7	ALPHA1O	Initial outer gimbal angles
8	ALPHA2O	
9	ALPHA3O	
10	BETA1O	Initial inner gimbal angles
11	BETA2O	
12	BETA3O	
13	KPHI	CMG system control law attitude and rate gains
14	KTHET	
15	KPSI	
16	KDPHI	
17	KDTHET	
18	KDPSI	
19		
20		
21		
22	APX	Constant anti-parallel moments
23	APY	
24	APZ	
25		
26	FUDGE	Constant to change spacecraft attitude recorder scale factor
27	GETI	Initial value of GET which is sampling interval for SMART
28	AKDP	Distribution gain for isogonal correction
29	AKR	Rotation gain for isogonal correction
30	TINC	Computing interval

TABLE B-3.- KEYBOARD INPUT VARIABLES - Concluded

<u>VAR</u>	<u>Variable name</u>	<u>Description</u>
31	FXO	Initial crew motion forces
32	FYO	
33	FZO	
34	MXO	Initial crew motion moments
35	MYO	
36	MZO	
37		
38	DUM1	Control variables to signal when gyro is in or out DUM2 = 1.0 - Gyro 2 is being used DUM2 = 0.0 - Gyro 2 has been shut down and is not being used
39	DUM2	
40	DUM3	
41	COMM1	PHI reference angle for experiment package control system
42	COMM2	THETA reference angle for experiment package control system
43	SFMAN	Hand controller gain for pitch axis
44	SYMAN	Hand controller gain for yaw axis
45	VTGAIN	Computer gain
46	ADEL	Total number of delta's used in recursion formulas
47	APE	Total number of points to be used in curve fit
<u>INTEG</u>	<u>Variable name</u>	<u>Description</u>
201	ISCAN	Number of computing intervals per scan cycle
202	IRECORD	Recorder selection number
<u>LOGIC</u>	<u>Variable name</u>	<u>Description</u>
301	IFLEX	.T. Calls flexibility equations .F. Skips flexibility equations
302	ISOG	.T. Isogonal correction in steering law .F. No isogonal correction
303	ISMART	.T. Call continuous monitor routine .F. Bypass system monitor
305	ISELECT	.T. SAD selection called .F. Skips SAD selection
306	IEXPACK	.T. Call experiment package .F. Does not call EXPACK
309	ICATIS	.T. Calls computer-augmented camera tracking routine .F. Skips CATIS
310	IHARD	.T. Hardware subroutine .F. Simulated system
311	ICMG1	.T. CMG 1 hardware .F. CMG 1 simulated
312	ICMG2	.T. CMG 2 hardware .F. CMG 2 simulated
313	ICMG3	.T. CMG 3 hardware .F. CMG 3 simulated
314	IRATEM	.T. Compute torques from actual CMG rates .F. Compute torques from commanded CMG rates
315	ITMS	.T. Torque measurement on hardware CMG rates .F. Computation of CMG torques from gimbal rates
316	ICONSOL	.T. Manual control console routine .F. Skip manual console
317	ICK	.T. Manual control console checkout (static check) .F. Skip console checkout
319	ICREW	.T. Call crew motion subroutine .F. No call for crew motion
320	LOADCEL	.T. Load cell signals for crew motion inputs .F. Tape signals for crew motion inputs

APPENDIX C

PROGRAM OUTPUT

This appendix is a discussion of the data output available from the space station dynamics program. A parameter listing and description, output formats, and explanations of output options are presented in tabular form. Data output facilities include Brush time history recorders, X-Y plotters, an on-line typewriter, and a high-speed line printer.

Recorder Output

Data recording equipment for the simulation consists of two time history recorders located adjacent to the program control station. Each time history recorder has eight analog and nine discrete channels. The analog channels are used to record desired data parameters. Two discrete channels (numbers 8 and 9) are used to record time. The remaining discrete channels may be used as event markers. There are four sets of time history output available on option. The desired set of output data is selected for each run by setting IRECORD from the program control station. A detailed outline of these recorder options is shown in table C-1. The first set of recorder output (IRECORD = 1) includes spacecraft rates and angles, commanded and output control torques, and unfiltered spacecraft moment commands. It should be noted that when CATIS is being used, this first recorder selection will substitute the tracking camera angles for the commanded moments about the X and Y spacecraft axes (channels 7 and 8).

The second set of recorder output (IRECORD = 2) consists of CMG gimbal angles and rates, and spacecraft total disturbance moments, MX, MY, and MZ. The third recorder selection (IRECORD = 3) is used when running in the EPS mode. The outputs include experiment package motions and torques. The fourth set of recorder outputs (IRECORD = 4) includes the servo table errors, crew motion forces and moments, and spacecraft angles. Total CMG system momentum is included for all recorder selections.

Typewriter Output

In conjunction with the time history recorders, there is a typewriter output available which is called on option from the RESET loop. This output provides the operator with immediate information concerning the selected recorder option. The printout, shown in table C-2, includes the recorder option number and all 16 channel numbers with associated parameter name, range, and unit of measurement.

TABLE C-1.- TIME HISTORY RECORDER OPTIONS

Parameter	Symbol	Scale factor	Range	Recorder channel	Parameter	Symbol	Scale factor	Range
IRECORD = 1					IRECORD = 2			
OMEGX	Ω_x	SFRO	2000 $\widehat{\text{sec/sec}}$	1	ALPHA1	α_1	SFRA	200 deg
OMEGY	Ω_y	SFRO	2000 $\widehat{\text{sec/sec}}$	2	ALPHA2	α_2	SFRA	200 deg
OMEGZ	Ω_z	SFRO	2000 $\widehat{\text{sec/sec}}$	3	ALPHA3	α_3	SFRA	200 deg
PHI	ϕ	SFRP	1000 FUDGE sec	4	BETA1	β_1	SFRA	200 deg
THET	θ	SFRP	1000 FUDGE sec	5	BETA2	β_2	SFRA	200 deg
PSI	ψ	SFRP	1000 FUDGE sec	6	BETA3	β_3	SFRA	200 deg
¹ MXC	M_{X_C}	SFRM	500 ft-lb	7	MX	M_x	SFRM	500 ft-lb
¹ MYC	M_{Y_C}	SFRM	500 ft-lb	8	MY	M_y	SFRM	500 ft-lb
GX	G_x	SFRM	500 ft-lb	9	DALF1	$\dot{\alpha}_1$	SFRR	10 deg/sec
MXFIL	M_{X_F}	SFRM	500 ft-lb	10	DALF2	$\dot{\alpha}_2$	SFRR	10 deg/sec
GY	G_y	SFRM	500 ft-lb	11	DALF3	$\dot{\alpha}_3$	SFRR	10 deg/sec
MYFIL	M_{Y_F}	SFRM	500 ft-lb	12	DBETA1	$\dot{\beta}_1$	SFRR	10 deg/sec
GZ	G_z	SFRM	500 ft-lb	13	DBETA2	$\dot{\beta}_2$	SFRM	10 deg/sec
MZFIL	M_{Z_F}	SFRM	500 ft-lb	14	DBETA3	$\dot{\beta}_3$	SFRM	10 deg/sec
MZC	M_{Z_C}	SFRM	500 ft-lb	15	MZ	M_z	SFRM	500 ft-lb
HT	H_T	SFHT	0.0 to 9000 ft-lb	16	HT	H_T	SFHT	0.0 to 9000 ft-lb
IRECORD = 3					IRECORD = 4			
PHDE	$\dot{\phi}_e$	SFX2	10 $\widehat{\text{min/sec}}$	1	TABLER1		SFAE	0.5 deg
PHDM	$\dot{\phi}_c$	SFPAC	10 $\widehat{\text{min/sec}}$	2	TABLER2		SFAE	0.5 deg
PHIE	ϕ_e	SFX3	50 $\widehat{\text{min}}$	3	TABLER3		SFAE	0.5 deg
PHIG	ϕ_G	SFX1	10 deg	4	TABLER4		SFRE	0.05 deg/sec
THDE	$\dot{\theta}_e$	SFX2	10 $\widehat{\text{min/sec}}$	5	TABLER5		SFRE	0.05 deg/sec
THDM	$\dot{\theta}_c$	SFPAC	10 $\widehat{\text{min/sec}}$	6	TABLER6		SFRE	0.05 deg/sec
THEE	θ_e	-SFX3	50 $\widehat{\text{min}}$	7	PHI	ϕ	SFRP	0.277 FUDGE deg
THEG	θ_G	SFX1	10 deg	8	THET	θ	SFRP	0.277 deg
PSIG	ψ_G	SFX4	250 deg	9	CMX	M_{C_X}	SFCON	50 ft-lb
PSDM	ψ_G	SFX5	20 deg/sec	10	CMY	M_{C_Y}	SFCON	50 ft-lb
PSI	ψ	SFX3	50 $\widehat{\text{min}}$	11	CMZ	M_{C_Z}	SFCON	50 ft-lb
OMEGZ	Ω_z	SFRO	$\pm 0.55 \text{ deg/sec}$	12	FXF	F_{C_X}	SFCON	50 ft-lb
GEX		SFGEX	50 ft-lb	13	FYF	F_{C_Y}	SFCON	50 ft-lb
GEY		SFGEY	50 ft-lb	14	FZF	F_{C_Z}	SFCON	50 ft-lb
GEZ		SFGEZ	20 ft-lb	15	PSI	ψ	SFRP	0.277 FUDGE deg
HT	H_T	SFHT	0.0 to 9000 ft-lb	16	HT	H_T	SFHT	0 to 9000 ft-lb

¹When using subroutine CATIS with IRECORD = 1 the angles ϕ_s and θ_s are recorded on channels 7 and 8 in place of M_{X_C} and M_{Y_C} as shown below:

SPHI	ϕ_s	SFDIS	8 rad	7
STHE	θ_s	SFDIS	8 rad	8

TABLE C-2.- TYPEWRITER PRINTOUT FOR TIME-HISTORY
RECORDER OPTION

SSDS IRECORD= 1 06/17/70 09.46.23.

CHANNEL	VARIABLE	RANGE	UNITS
1	OMEGX	2.000000E+03	ARC/SEC
2	OMEGY	2.000000E+03	ARC/SEC
3	OMEGZ	2.000000E+03	ARC/SEC
4	PHI	1.000000E+03	ARCSEC
5	THET	1.000000E+03	ARCSEC
6	PSI	1.000000E+03	ARCSEC
7	MXC	5.000000E+02	FT-LB
8	MYC	5.000000E+02	FT-LB
9	GX	5.000000E+02	FT-LB
10	MXFIL	5.000000E+02	FT-LB
11	GY	5.000000E+02	FT-LB
12	MYFIL	5.000000E+02	FT-LB
13	GZ	5.000000E+02	FT-LB
14	MZFIL	5.000000E+02	FT-LB
15	MZC	5.000000E+02	FT-LB
16	HT	9.000000E+03	FT-LB

NOTE.

HT RANGE IS +

ALL OTHERS ARE + AND -.

SSDS IRECORD= 4 06/17/70 09.48.01.

CHANNEL	VARIABLE	RANGE	UNITS
1	TABLER1	5.000000E-01	DEG
2	TABLER2	5.000000E-01	DEG
3	TABLER3	5.000000E-01	DEG
4	TABLER4	5.000000E-02	DEG/SEC
5	TABLER5	5.000000E-02	DEG/SEC
6	TABLER6	5.000000E-02	DEG/SEC
7	PHI	1.000000E+03	ARCSEC
8	THET	1.000000E+03	ARCSEC
9	CMX	5.000000E+01	FT-LB
10	CMY	5.000000E+01	FT-LB
11	CMZ	5.000000E+01	FT-LB
12	FXF	5.000000E+01	FT-LB
13	FYF	5.000000E+01	FT-LB
14	FZF	5.000000E+01	FT-LB
15	PSI	1.000000E+03	ARCSEC
16	HT	9.000000E+03	FT-LB

NOTE.

HT RANGE IS +

ALL OTHERS ARE + AND -.

APPENDIX C – Concluded

Printer Output

A block of output data is stored on a disk file at specified time intervals denoted by the integer variable **NT** in terms of iteration cycles. Upon completion of the run, all output may be routed to a printer by depressing the print control button located on the program control station. A listing and description of these output variables are shown in table C-3.

TABLE C-3.- LINE PRINTER OUTPUT VARIABLES

<u>Variable name</u>	<u>Description</u>
T	Time
OMEGX,OMEGY,OMEGZ	Total spacecraft rates
PHI,THET,PSI	Total spacecraft Euler angles
OMEGXR,OMEGYR,OMEGZR	Rigid body rates
PHIR,THETR,PSIR	Rigid body Euler angles
OMEGXF,OMEGYF,OMEGZF	Flexible body rates
PHIS,THETS,PSI	Flexible body Euler angles
DOMEGXR,DOMEGYR,DOMEGZR	Rigid body accelerations
DPHIR,DTHETR,DPSIR	Rigid body rates
ALPHA1,ALPHA2,ALPHA3	Outer CMG gimbal angles
BETA1,BETA2,BETA3	Inner CMG gimbal angles
DALF1,DALF2,DALF3	Outer CMG gimbal rates
DBETA1,DBETA2,DBETA3	Inner CMG gimbal rates
GX,GY,GZ	Control torques
MXC,MYC,MZC	Command torques
HXC,HYC,HZC	Commanded momentum
HX,HY,HZ	Total CMG momentum
HXE,HYE,HZE	Momentum error

REFERENCES

1. Kurzhals, Peter R.; and Grantham, Carolyn: A System for Inertial Experiment Pointing and Attitude Control. NASA TR R-247, 1966.
2. Kennel, Hans F.: Individual Angular Momentum Vector Distribution and Rotation Laws for Three Double-Gimbaled Control Moment Gyros. NASA TM X-53696, 1968.
3. Anderson, Willard W; Will, Ralph W; and Jacobs, Kenneth L.: A Computerized Onboard Expedition Monitor and Maintenance Analyst (EMMA) for Spacecraft Systems. NASA TN D-5725, 1970.

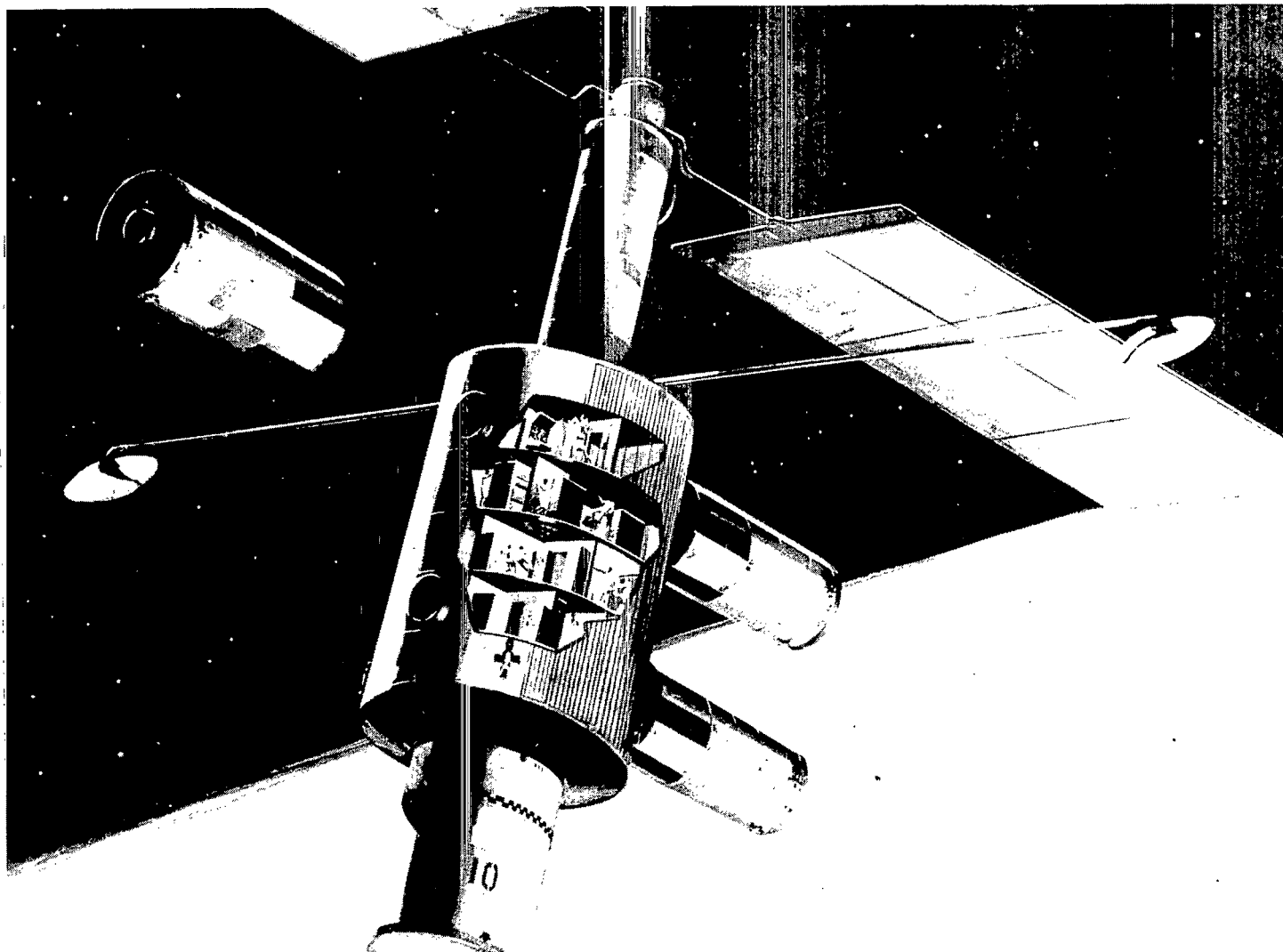


Figure 1.- Typical space station configuration.

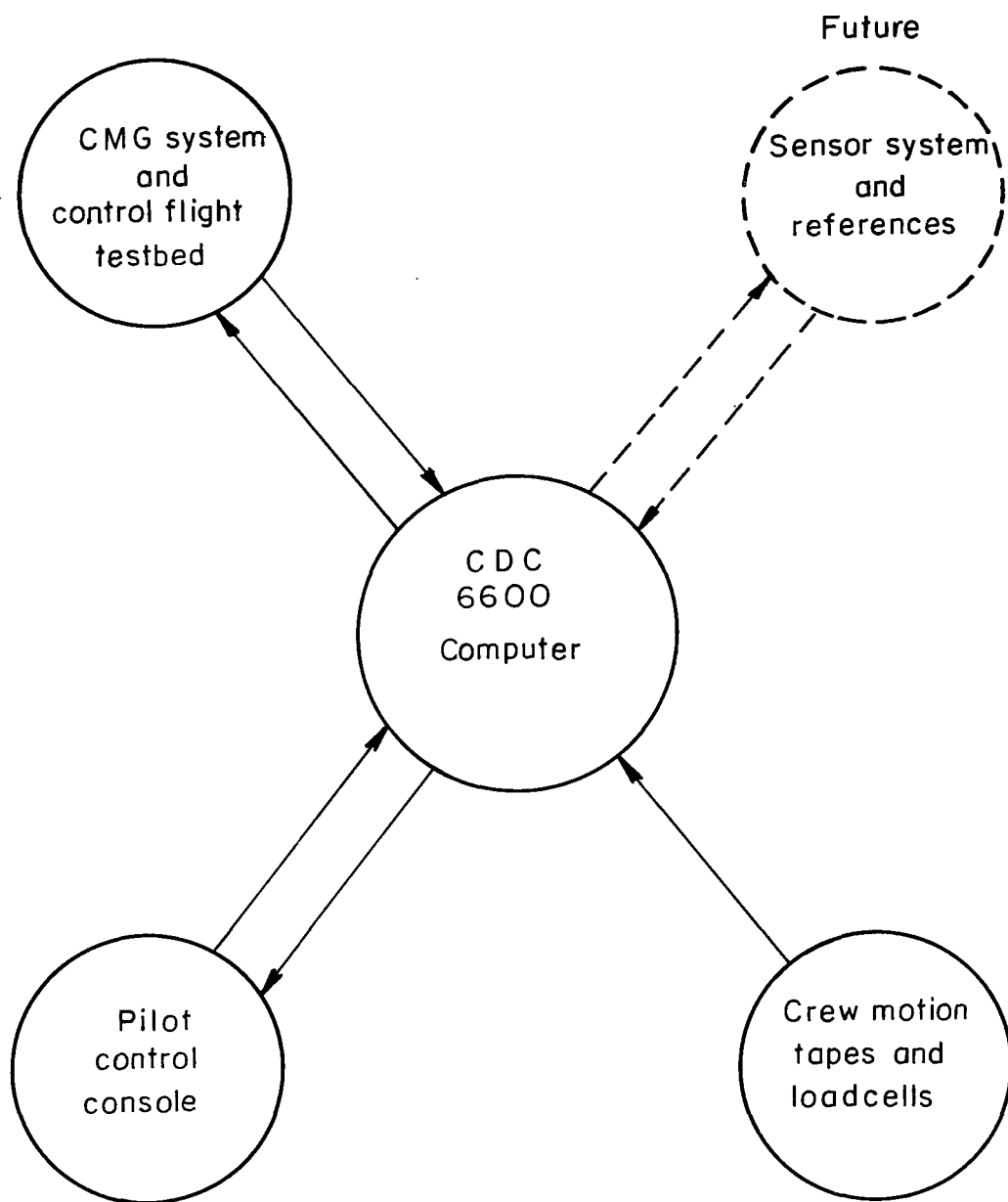


Figure 2.- Schematic of space station dynamics simulation.

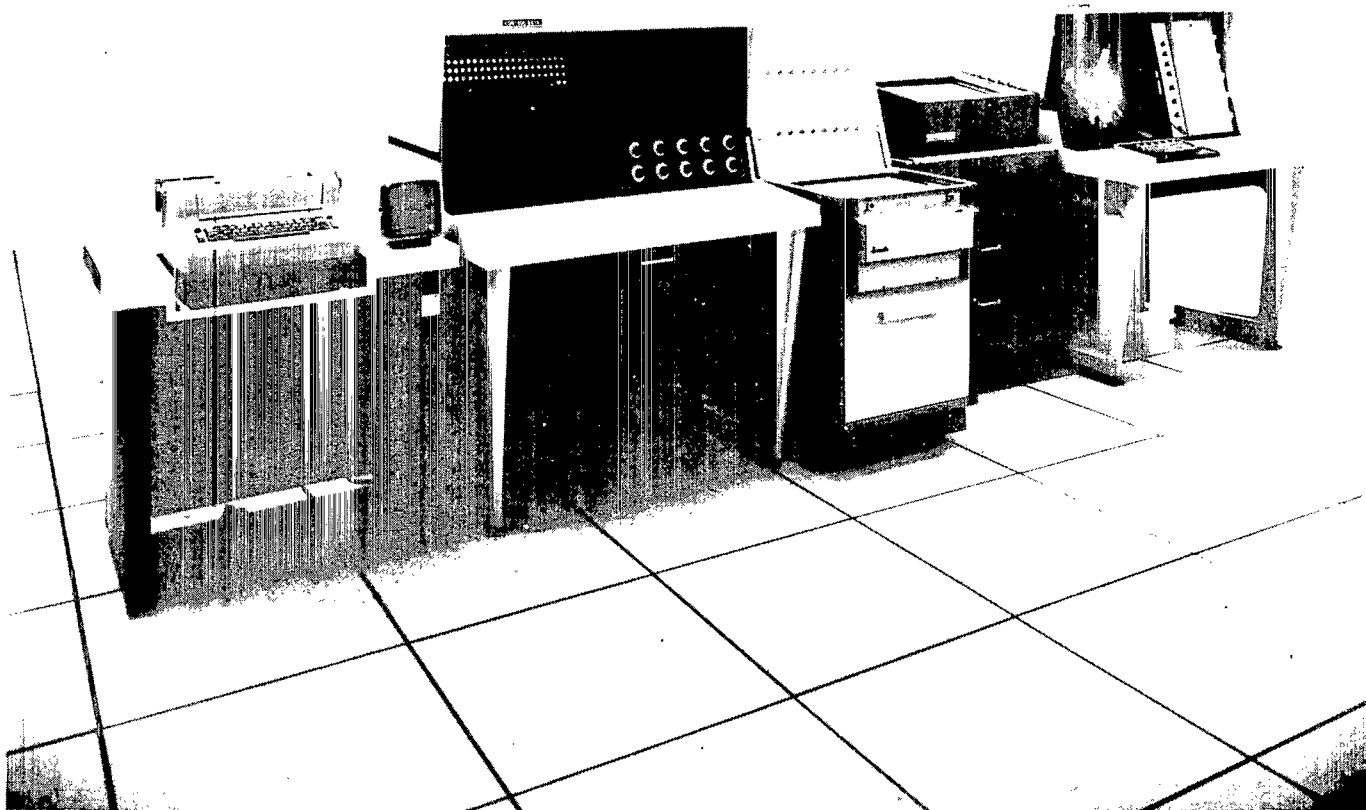


Figure 3.- Simulation control station.

L-71-651

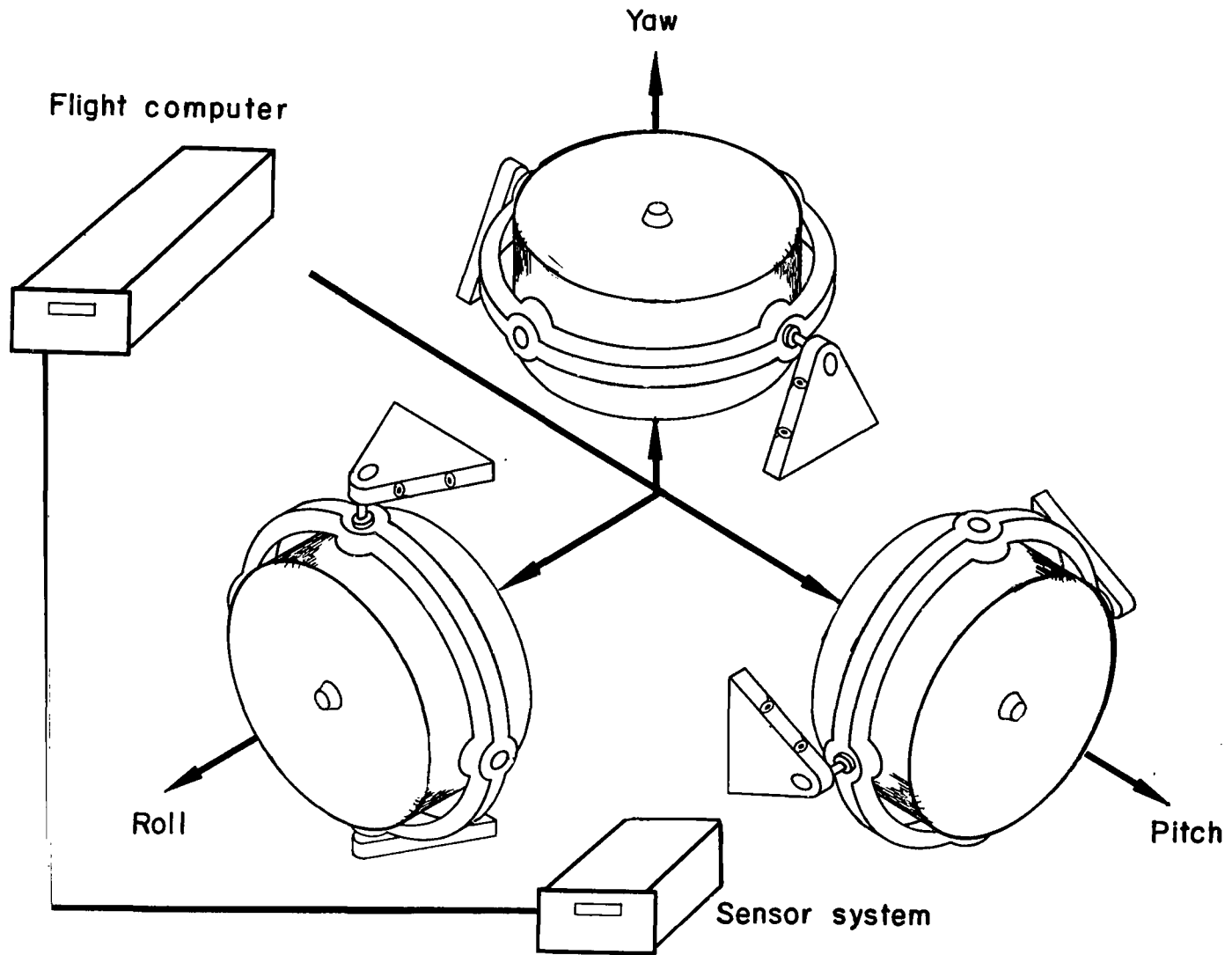


Figure 4.- Schematic of CMG system.

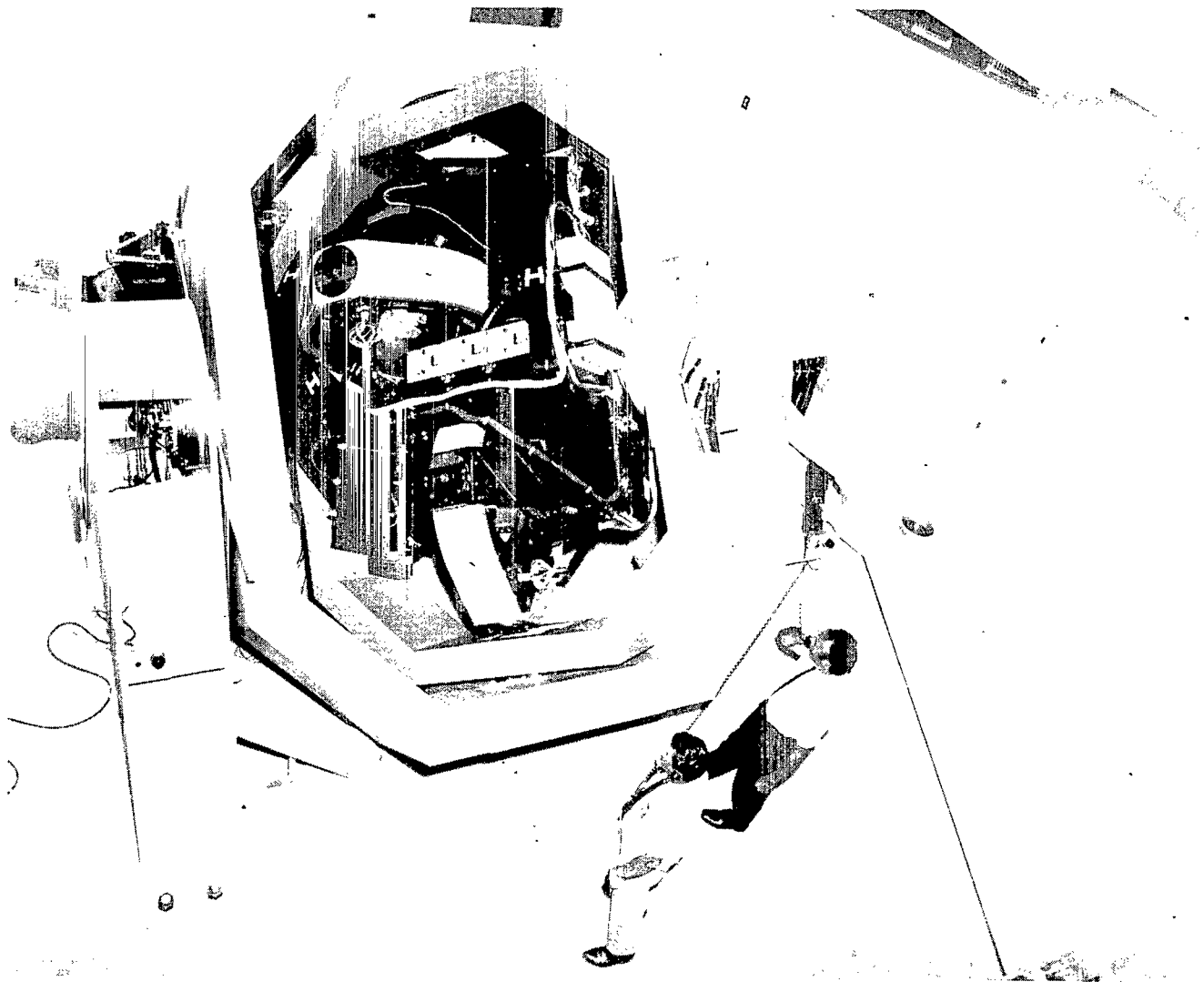


Figure 5.- CMG hardware mounted on moving base simulator.

L-69-4961



Figure 6.- Space station manual control console.

L-69-5437

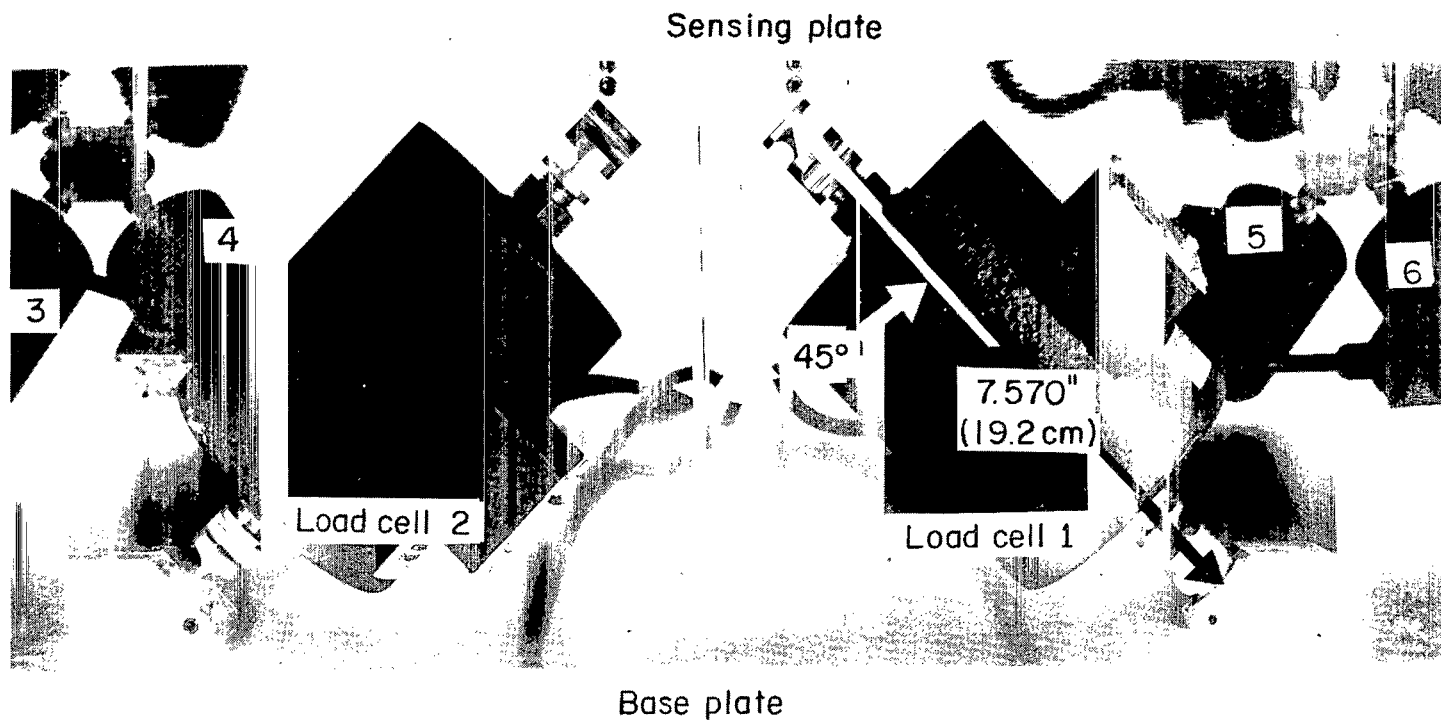


Figure 7.- Manual couch load cell array.

L-71-652

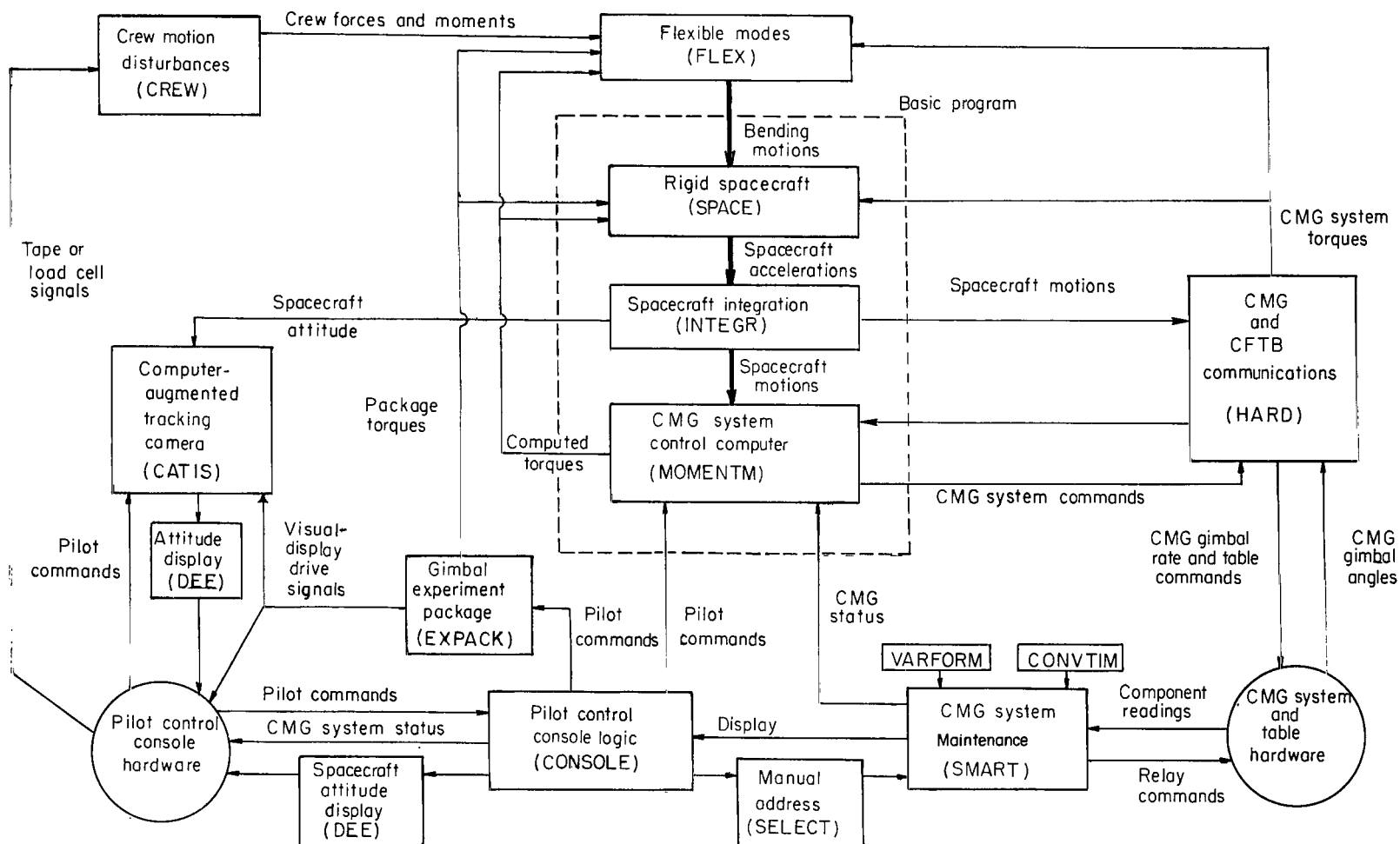


Figure 8.- Space station dynamics simulation software block diagram.

09/19/69 08.18.42.
 CMG SYSTEM FAILURE DETECTED
 +28 VOLT * CMG 3 * AV READING= .011
 POWER SUPPLY REPLACED

09/19/69 08.19.30.
 CMG SYSTEM FAILURE DETECTED
 +26 VOLT * CMG 3 * AV READING= .011
 POWER SUPPLY REPLACED

09/19/69 08.21.39.
 CMG SYSTEM FAILURE DETECTED
 +15 VOLT * CMG 3 * AV READING= .007
 POWER SUPPLY REPLACED

09/19/69 08.24.13.
 CMG SYSTEM FAILURE DETECTED
 + 5 VOLT * CMG 3 * AV READING= .009
 POWER SUPPLY REPLACED

09/19/69 08.24.28.
 CMG SYSTEM FAILURE DETECTED
 SPIN CURRENT * CMG 3 * AV READING= .037
 CMG FAILED
 MANUAL ASSISTANCE REQUESTED

CMG SYSTEM CRITICAL FAILURE

CMG SYSTEM SHUT DOWN - RCS SYSTEM ACTIVATED
 REQUEST MANUAL CHECKOUT

09/19/69 08.28.11.
 CMG SYSTEM FAILURE DETECTED
 RIGHT BEARING TMP* CMG 1 * AV READING= -5.427
 CMG FAILED
 MANUAL ASSISTANCE REQUESTED

Figure 9.- On-line typewriter result for SMART operation.

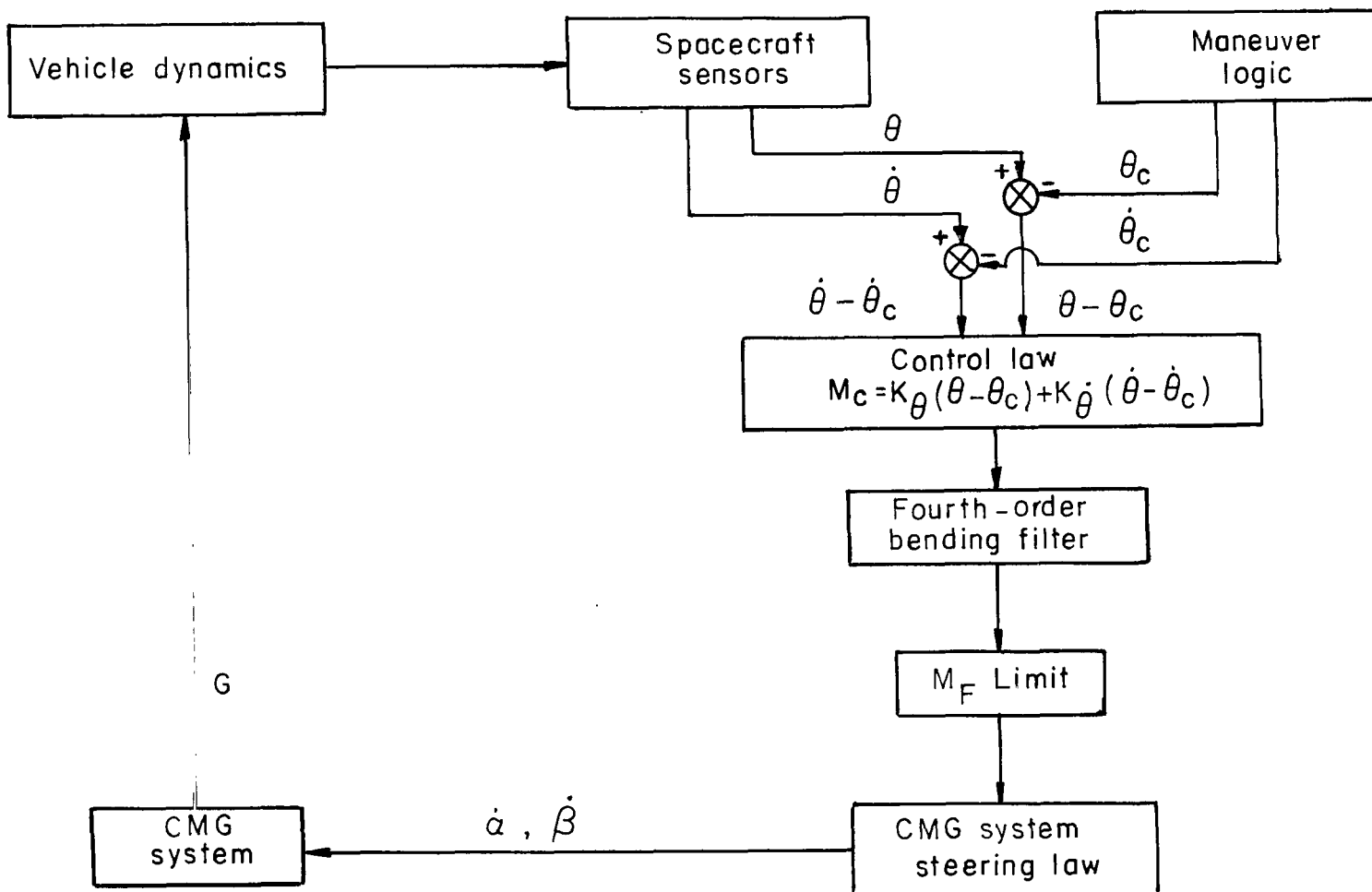


Figure 10.- Control loop schematic.

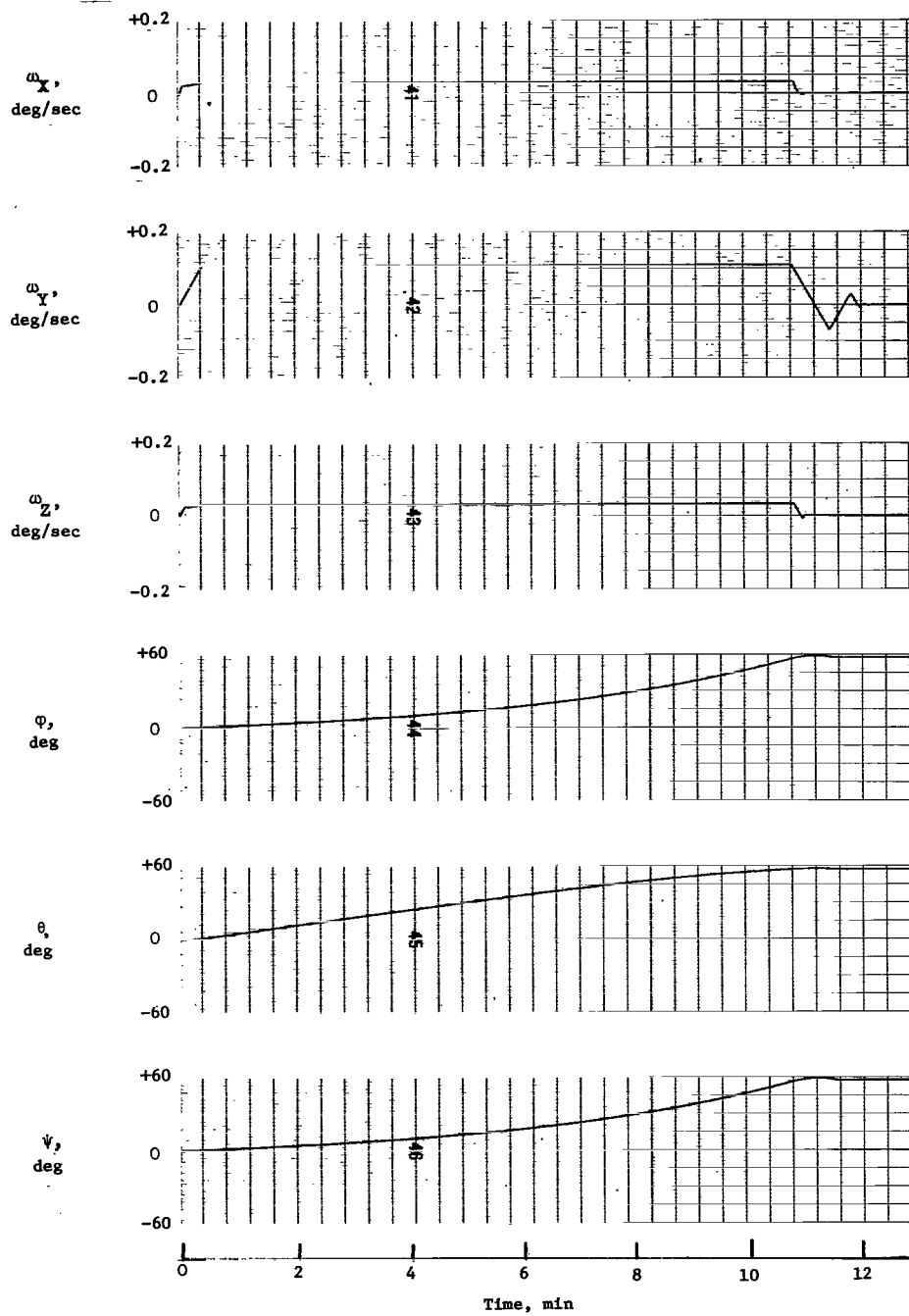


Figure 11.- Three-axis simultaneous 57.3° maneuver.

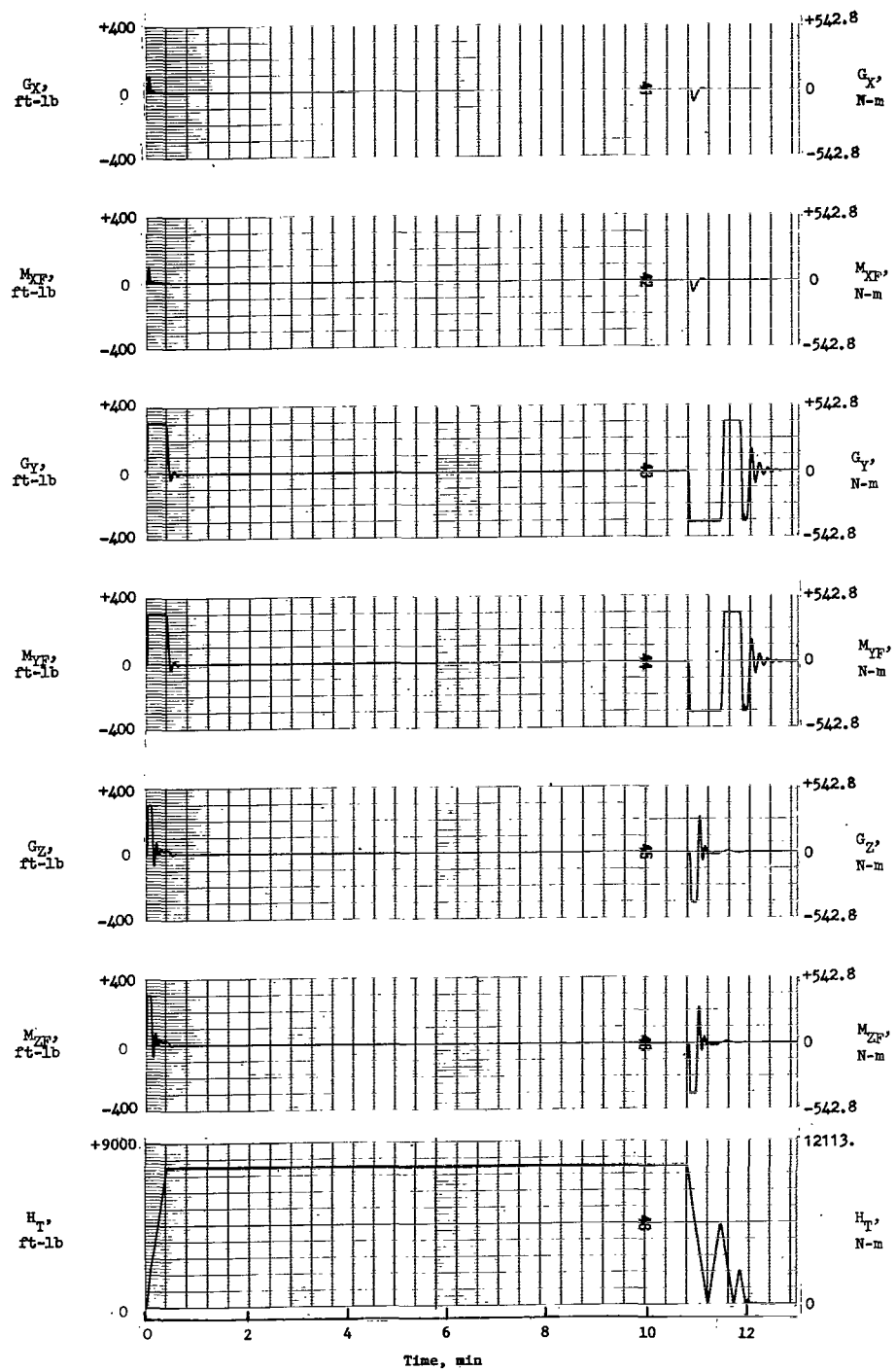


Figure 11.- Concluded.

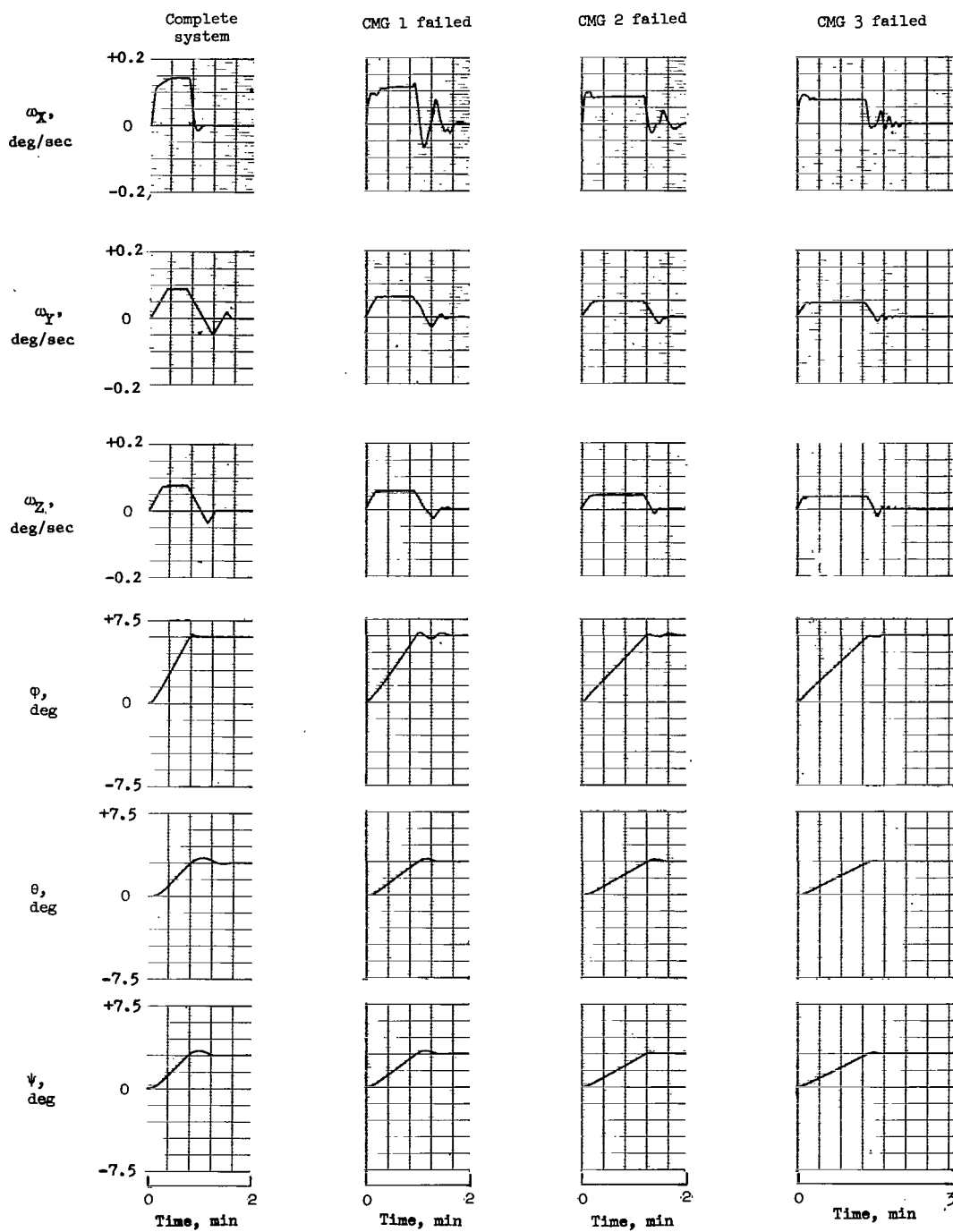
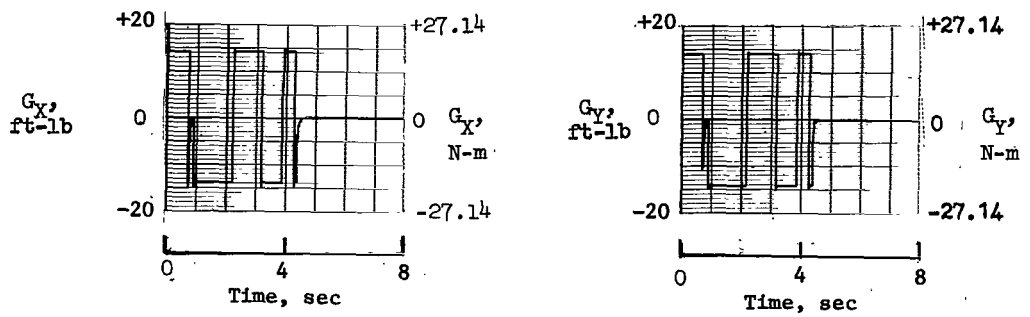
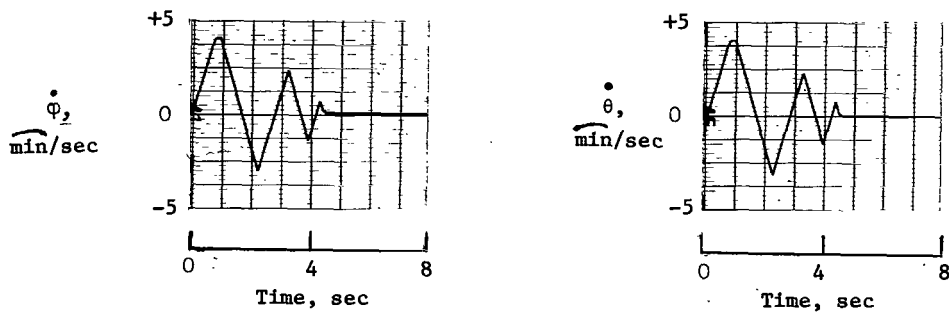


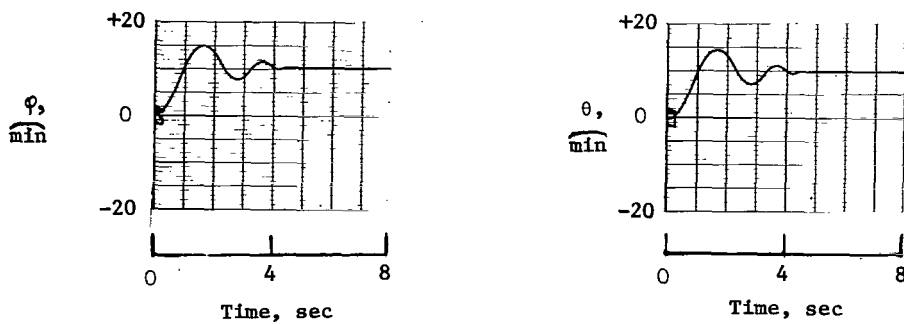
Figure 12.- Simultaneous three-axis 6°, 3°, 3° maneuver with CMG failures.



(a) Experiment package torques.

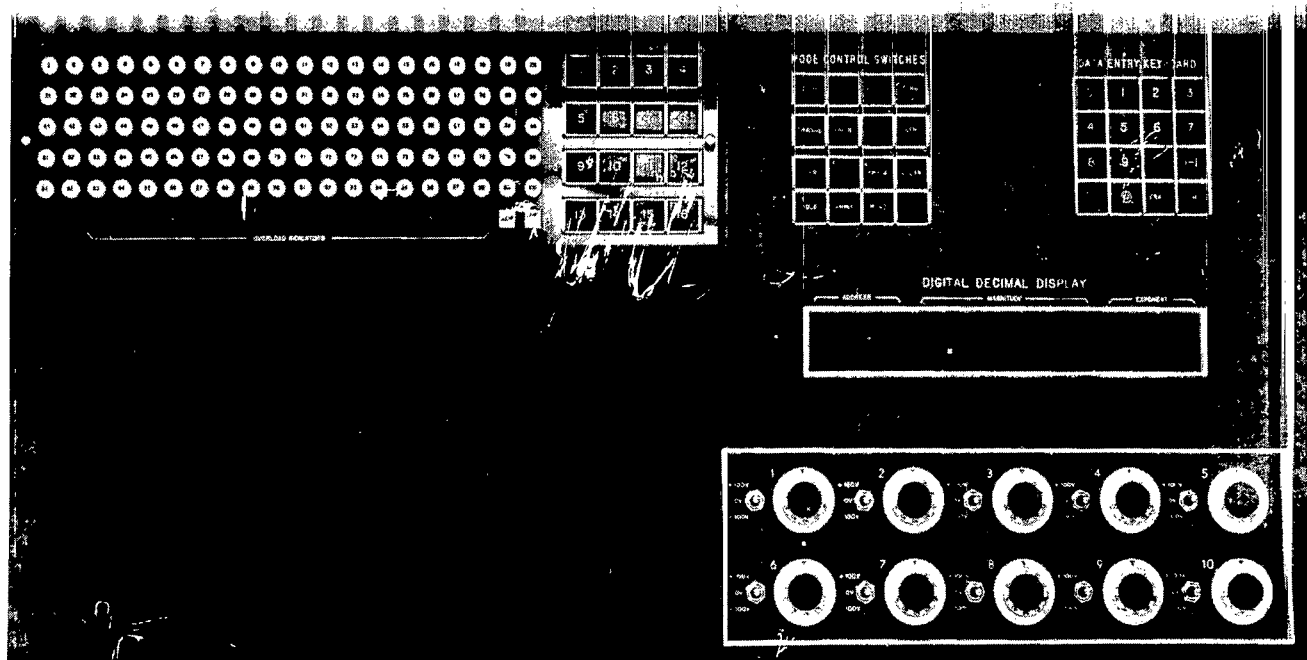


(b) Experiment package rates.



(c) Experiment package inertial angles.

Figure 13.- Experiment package response to a step input of 10 min .



L-69-4971

Figure 14.- Closeup photograph of the control panel on the simulation control station.

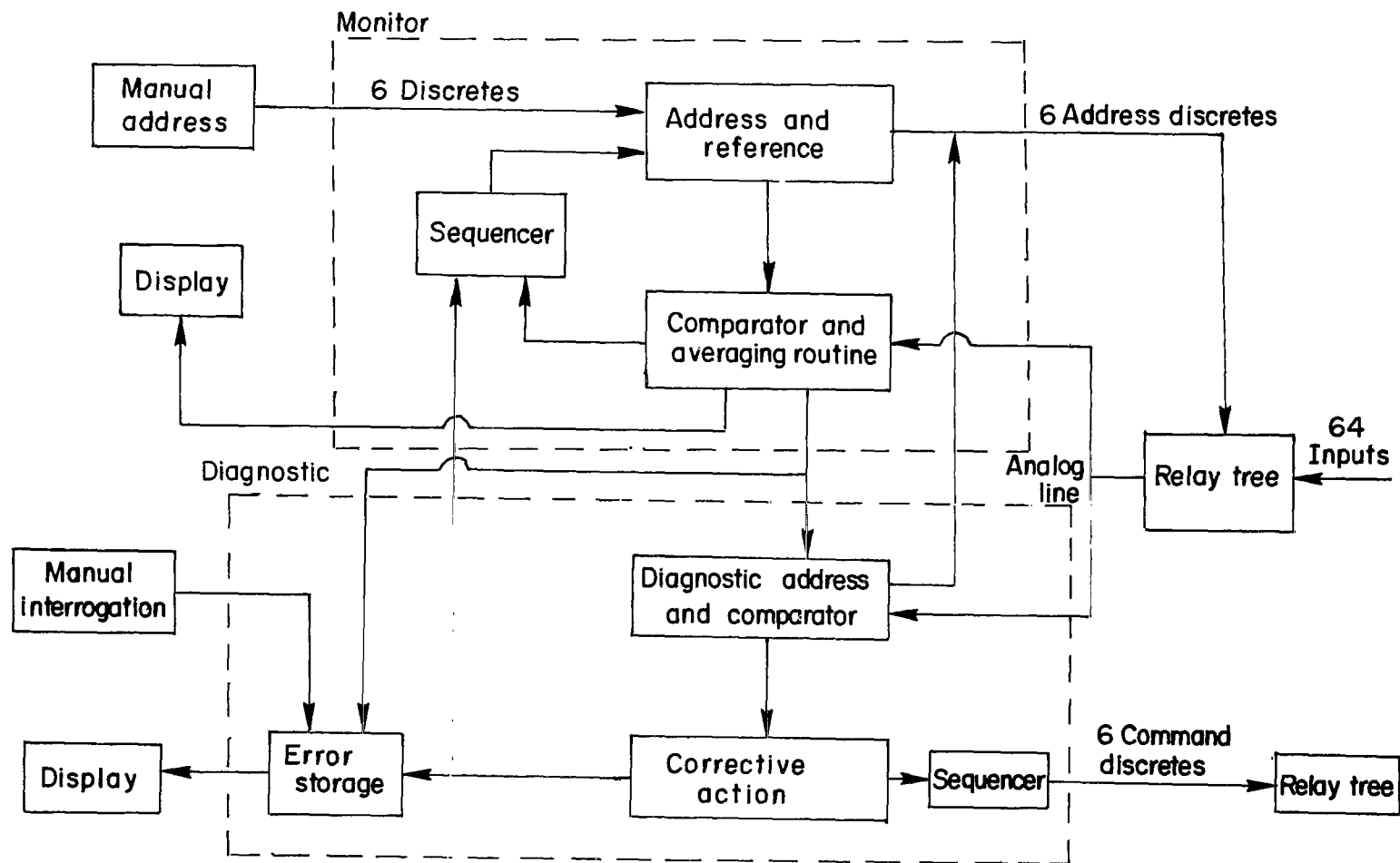


Figure 15.- Functional block diagram of EMMA system.

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